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THE RIGGING MAINTENANCE AND INSPECTION OF AIRCRAFT

("A" LICENCE)

BY

W. J. C. SPELLER

The Air Ministry, whilst accepting no responsibility for the contents of this book, recognizes it as a textbook that should prove to be of value to intending applicants for Ground Engineers' licences

FOREWORD

By Captain A. E. STEELE

"Any such aircraft flying for public service shall not fly unless it has within twenty-four hours been inspected and certified as safe for flight . . ."

"An inspection under this paragraph shall be carried out by a competent person licensed for the purposes of this Schedule . . . etc. . . ."

The above extracts from the Air Navigation (Consolidation) Order, 1923, will serve as an introduction to this foreword dealing with the examination of applicants for Ground Engineers' licences valid in Category "A."

Having made up his mind to become licensed as a person competent to inspect and certify an aeroplane before flight, the prospective ground engineer should communicate with the Secretary (D.C.A.) Air Ministry, asking to be supplied with a form of application.

In due course he will be supplied with a copy of C.A. Form 2.B. together with a copy of A.M. Pamphlet 34. The latter is entitled "Instructions to Applicants for Ground Engineers' Licences and Syllabus of Examinations." It informs the applicant that he must provide himself with copies of the Air Navigation (Consolidation) Order, 1923, and the Air Navigation Directions, and clearly indicates that these publications are to be studied and digested before he presents himself for examination. It recommends that he obtain a copy of the Airworthiness Handbook for Civil Aircraft (A.P. 1208).

From the foregoing remarks it will be appreciated that the first thing to be done by the aspirant for a ground engineers' licence is to become acquainted with the statutory rules and regulations which govern Civil aviation. The publications with which he is instructed by A.M. Pamphlet 34 to provide himself, detail the duties and qualifications of ground engineers. They are obtainable from H.M. Stationery Office in London, Edinburgh, Manchester, Cardiff, and Belfast, or through any bookseller.

From a perusal of these publications he will learn the qualifications which are necessary. Briefly stated, he should have attained the age of twenty-one years, and he must have had such practical experience as in the opinion of the Secretary of State will enable him to perform the duties for which the licence is required. A.M. Pamphlet 34 details the syllabus of the examination for Category "A," and the applicant should be able to appreciate that considerable practical experience of

rigging, maintenance, and inspection of aircraft must be obtained to enable him to pass the examination.

When the applicant has completed the application form, he will forward it as directed thereon, accompanied by the appropriate fees, to the Secretary (D.C.A.) Air Ministry.

If, from a perusal of the particulars given on the application form, it is decided that the applicant can be accepted, he will be requested to present himself for examination either in London or at some more convenient centre in the provinces.

On his appearance before the examination board the candidate will first be questioned with a view to testing his knowledge of the regulations and of the duties, as governed by the regulations, for which he requires to be licensed.

The possession of the ground engineer's licence valid in Category "A" authorizes the holder to certify that an aircraft of a type or types stated on his licence has been properly inspected and is in a satisfactory condition for flight.

To enable him to do this he must be in a position to know that the aircraft which he is about to certify has been properly assembled and correctly rigged, that it has been properly maintained and that any repairs or essential modifications (the incorporation of which it is pointed out is outside the scope of a Category "A" licence) have been carried out in a satisfactory manner as duly recorded and certified by a ground engineer licensed to do so.

If any new parts or components have been fitted, he must be able to produce evidence, documentary or otherwise, to show that such parts or components are true to the type and made correctly in accordance with specifications and drawings. For this purpose he should have some knowledge of the system whereby certain firms and manufacturers have received Air Ministry approval of their inspection organizations, and are thus authorized to issue "release notes" covering goods supplied by them and certifying their compliance with the relevant specifications and drawings.

He must ensure that any modifications, the need for which has been notified by means of Notices to Aircraft Owners and Ground Engineers as applicable, have been correctly embodied. Conversely, he must be satisfied that no unauthorized modification has been incorporated.

It will be found that the regulations provide detailed information concerning the procedure to be followed with regard to modifications to civil aircraft.

He must satisfy himself that the aircraft log book is properly maintained and that it provides a connected history of the life of the aircraft. Entries should be made to show how the aircraft has been used, the amount of flying done, and any repairs, replacements,

modifications, or overhauls carried out, together with references to release notes, notices to Aircraft Owners and Ground Engineers, etc., which may be applicable. Before a ground engineer can finally certify that a particular aircraft is in all respects in a satisfactory condition for flight, he must not only be satisfied that it is correctly assembled and rigged, he must also ensure that its equipment, in the light of the flight which it is about to make, is in accordance with the regulations. Other features must be taken into consideration, the Classification of the Aircraft as shown by the Certificate of Airworthiness, the number of seats, the type of accommodation, i.e. open cockpit or enclosed cabin, the type of aircraft, i.e. whether landplane, seaplane, or amphibian, all have a bearing on the nature of the equipment to be carried, and by the term "equipment" is meant not instruments only, but such items as safety belts, fire extinguishers, etc.

The Air Navigation Directions provide full information in respect of the equipment to be carried in varying circumstances.

Having finally satisfied himself that the aircraft is in all respects in a satisfactory condition in accordance with the regulations, he is in a position to complete his certificate. The questions thereupon arise—what form of wording is he to use for his certificate? How many copies are to be made out? How are they to be disposed of? How long are they valid? How long must they be retained?

The Ground Engineer must know the answers to all these questions. The Air Navigation (Consolidation) Order, 1923, and the Air Navigation Directions provide the information, but it is impracticable to expect the Ground Engineer to be in a position of having to refer to these publications at every turn. He has no right to expect to have a licence issued to him unless he can show that he has made himself familiar with the regulations, any more than he can expect to have a licence if he cannot show that he can rig or maintain a given aircraft.

He is taking on a responsible job and he must be able to deal with it in all its aspects.

He must understand that the regulations to which he must conform, and with which he must therefore be conversant, have not been drawn up casually or in any haphazard manner to meet the needs of this country alone. He will find that they have been produced as a result of considerable thought and after a great deal of discussion between representatives of most of the nationalities of the world. Once these facts have been appreciated it is hoped that the aspirant for a ground engineer's licence will realize why so much importance is attached to a sound knowledge of the regulations which govern Civil Aviation.

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He is relying on a [illegible] and he must be [illegible] with [illegible] aspects.

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PREFACE

An "A" licensee is required to be conversant with the Air Navigation Directions and Statutory Rules and Orders so far as they are applicable to his duties. He is required to have had sufficient practical experience in aircraft maintenance and/or construction and to have a knowledge of all the subjects dealt with in Chapters I and II, and 16 and 17 of Chapter IV herein, these being the minimum requirements. The whole subjects of Chapters III and/or V and/or either or both 18 and 19 (which is usually divided—ashore or afloat) of Chapter IV may be included in, or may form an extension of a Category "A" licence. The subjects (with the exception of the electrical section, which is also a part of Category "X") individually may be made an extension of the whole or any one of the Ground Engineers' licences, Categories "A," "B," "C," "D," and "X."

"A" licences are usually granted in respect of specific kinds and types of aircraft. In this book the subjects have been fully treated; indeed, in many cases they will be found more comprehensive than the requirements of an examining board demand.

This book will be found of service to Air Forces, to the staffs and students of Schools, Colleges, Universities, and Training Institutions; personnel in workshops, at aerodromes and seaplane bases; juniors and apprentices and all who desire a sound and thorough knowledge and understanding of everything appertaining to the practical maintenance of heavier-than-air craft.

The author is deeply indebted to Mr. T. C. L. Westbrook, General Manager of the Supermarine Aviation Works (Vickers), Ltd., whose help in the preparation of the text and many of the illustrations has been invaluable.

His thanks are also due to Mr. H. H. Cadman for many helpful suggestions and revision of the proofs.

Acknowledgment has also to be made of the courtesy and assistance received from Vickers (Aviation), Ltd., Mr. T. S. Duncan, Messrs. Reid and Sigrist, and Bendix, Ltd., in supplying information regarding their products.

CONTENTS

CHAPTER V

GENERAL SERVICE ELECTRICAL INSTALLATION INCLUDING CONTINUITY AND INSULATION TESTS

APPENDICES

THE RIGGING MAINTENANCE AND INSPECTION OF AIRCRAFT

By W. J. C. SPELLER

CHAPTER I

1. ASSEMBLY OF AIRCRAFT STRUCTURE AND RIGGING ADJUSTMENT AND CHECK

Fuselage Rigging Adjustment and Check

The first component in the assembly of a landplane is the fuselage, and it is assumed here that this component is correctly assembled and truly

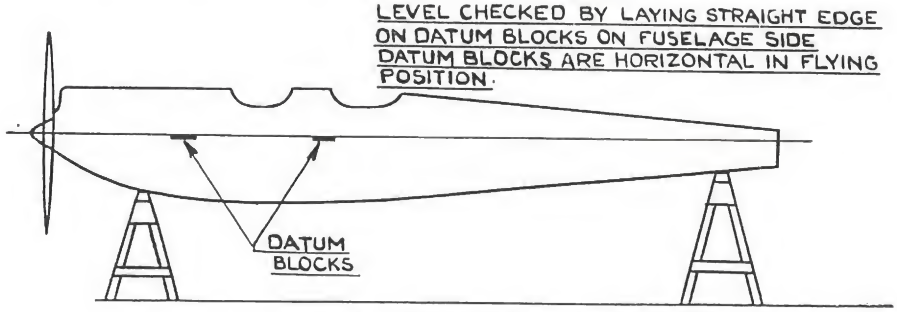

Fig. 1. Rigging Position

rigged. The fuselage should be placed on trestles and arranged longitudinally and laterally approximately level, allowing sufficient height to enable the undercarriage to be attached. The supporting trestles must be placed under the jacking blocks, which are usually situated near the front undercarriage struts, and at the rear of the fuselage near the tail skid. The fuselage when correctly positioned for assembly of the superstructure is said to be in the "rigging position" (see Fig. 1).

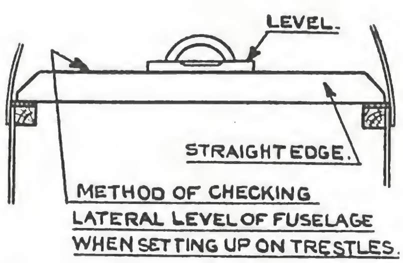

Fig. 2. Fixed Levelling Blocks

The "rigging position" is indicated in the rigging notes contained in the maker's handbook, or on the rigging diagram supplied for each type of aircraft. Datum lines or fixed levelling blocks (see Figs. 1 and 2) are now provided on all modern aircraft, and they enable the rigger easily to set the fuselage into correct position both longitudinally and laterally. When level the fuselage should be securely anchored.

Undercarriage

Now attach the undercarriage, which is usually rigged so as to be symmetrical about the centre line of the fuselage both in front and plan view. Undercarriages vary in design and construction, for small aircraft they usually consist of two side struts forming a "V" each side, axles, shock-absorbing devices, and cross bracings of flexible cable or streamline wire. For truing up the undercarriage the cross bracings should be adjusted to be equal in length; check this by the use of trammels, next drop plumb lines from the longerons on to the axle tube, and measure to the inside of the wheel flanges (see Fig. 3).

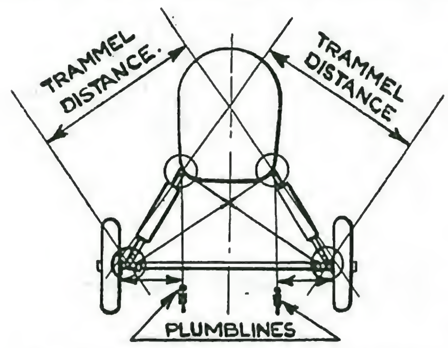

FIG. 3. TRUING UP UNDERCARRIAGE

When equal in length on each side the axle is central. Another method of checking can be made (1) from the outside of the wheel hub flange to some point in the centre of the fuselage between the undercarriage and sternpost, and (2) from the axle cap to some important fitting on the underside of the lower planes.

Centre Section

This is usually the next component to be erected, and if the struts are wooden members they must be carefully fitted and "bedded" in the strut sockets.

This unit can be roughly assembled on the ground and lifted into position. The loose ends of the struts are next attached to their respective fittings on the fuselage, and the ends of the bracing wires and struts are connected up.

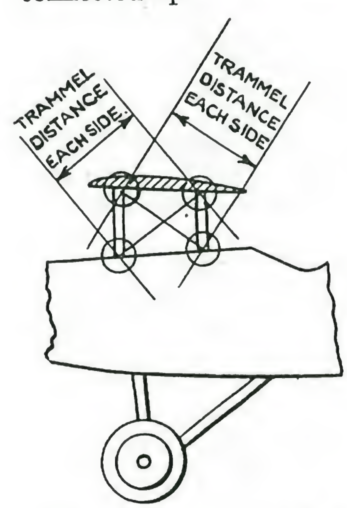

FIG. 4. TRUING UP TOP CENTRE PLANE

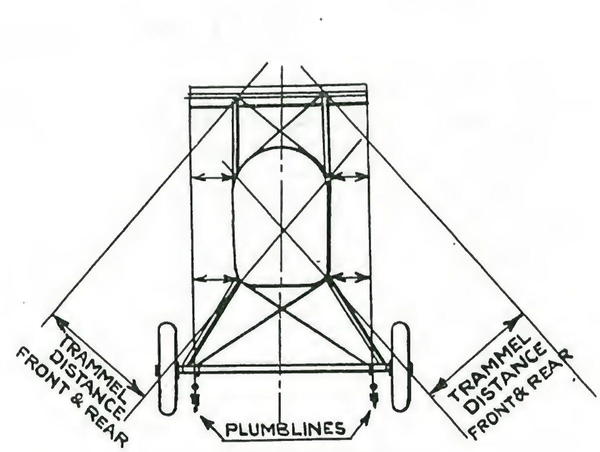

FIG. 5. TRUING UP TOP CENTRE PLANE

Truing Up the Centre Section

To true up the centre section, trammel the front, side, and rear diagonals (see Figs. 4 and 5) until the leading edge is horizontal and symmetrical

about the vertical centre line of the aeroplane, and is correctly (if applicable) staggered relative to the bottom plane position. The bracing wires are to brace the structure correctly and must not be used otherwise to pull a plane into its correct position or incidence.

Checking the Centre Section After Rigging

Drop plumb lines from the spar wing attachment fittings, front and rear, right and left sides, and measure to the fuselage. The measurement should be the same each side. To check the stagger, drop plumb lines over the leading edge of the top centre section and measure to the leading edge of the stub wing, or from the existing line from the top wing attachment fittings, measure to the lower wing attachment fittings on the fuselage. These dimensions should be equal on both sides and correct with the requirement laid down in the aircraft rigging diagram.

Attaching Main Planes (Medium biplane two-bay types)

The lower plane should be placed in a position with its chord vertical, care being taken not to damage the fabric or protective coating on the leading edge. Next fit the interplane struts, taking special precautions, where the diameters and lengths of the struts vary, that they are in their correct positions. The upper main plane should then be positioned to the lower plane so that the interplane struts may be attached. The bracing wires should then be joined to their respective fork ends and great care taken to see that these attachments are in their correct positions. Remember that the flying wires (which may be duplicated) are usually of a heavier gauge than the landing wires. Enter the wires carefully into the fork ends and commence turning, noting that the same number of threads are engaged at each end.

Having now boxed up the planes into a fairly rigid structure, lift into position, connect up the spar attachments, and then join up the bracing wires for the inner bay, first the inner landing wires from the top centre section to the bottom of the inner pair of interplane struts. Adopt the same method for each side to complete the assembly of the main planes. For method of mounting the main planes of seaplanes having a single set of struts, and for the larger multi-bay machines, see Chapter IV, "Rigging and Assembly of Flying Boats."

Truing Up the Main Planes

In most cases the aircraft manufacturers provide levelling, incidence, and dihedral boards (see Figs. 6 and 7), to enable a rapid and accurate

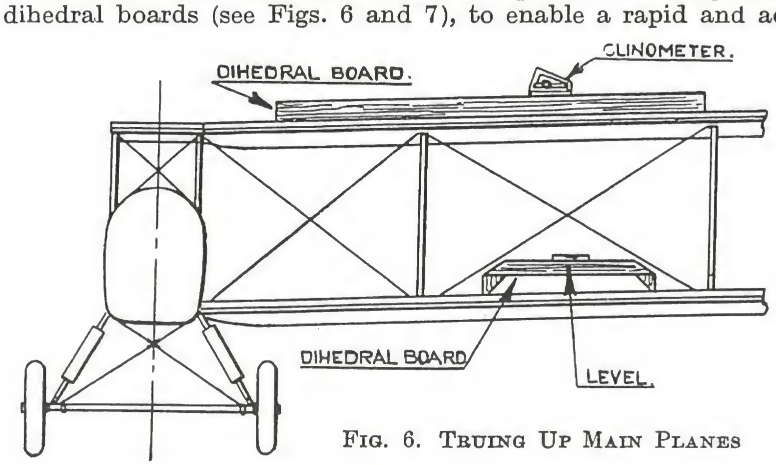

FIG. 6. TRUING UP MAIN PLANES

check to be made of the incidence and dihedral angles. If these special boards are not available, angles should be checked by using a straight edge and clinometer (also shown in Figs. 6 and 7).

The dihedral angle of the main plane is fixed by the adjustment of the front landing wires, and is checked by means of dihedral board or straight edge and clinometer over the front spar.

The stagger is adjusted by the cross bracing between the front and rear interplane struts, and is checked by measuring horizontally the dis-

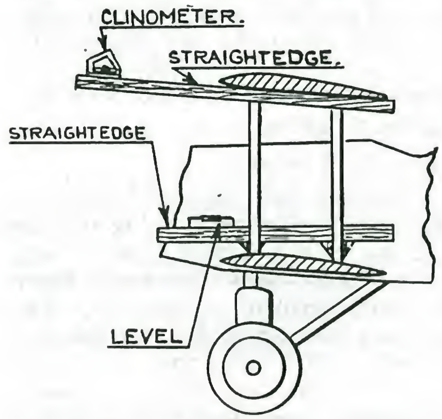

FIG. 7. TRUING UP MAIN PLANES

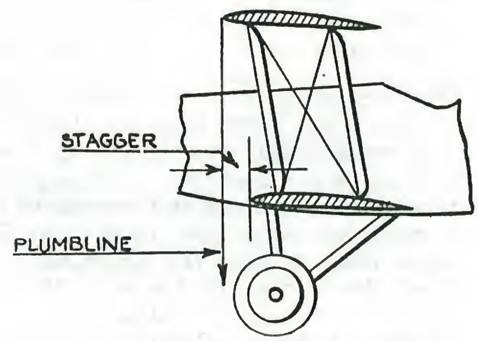

FIG. 8. MEASURING STAGGER

tance of a plumb line dropped from the leading edge of the upper main plane to the leading edge of the lower main plane (see Fig. 8).

The incidence of the main planes is adjusted chiefly by means of the rear landing wires, in conjunction with the incidence bracing between the front and rear interplane struts. The incidence is checked by using the special board with a level, or by means of a clinometer resting in a straight edge which is held up under the main plane and along one of the ribs (see Fig. 6).

When the dihedral and incidence angles, on each side, and the stagger are all correct, the planes have to be checked to see that they are symmetrical with the fuselage by measuring from points at the upper and lower outer front strut fitting to the stern post and the centre of the airscrew shaft.

Truing Up the Tail Unit

The tail plane is laterally horizontal and is symmetrical about the centre line of the fuselage. This component is checked transversely with a straight-edge and spirit level (see Fig. 9), if the spars are tapered packing blocks are necessary. The incidence must be checked by using a special board and a clinometer (see Fig. 10), and if the aircraft is fitted with an adjustable tail plane the incidence in the upper and lower positions must also be checked.

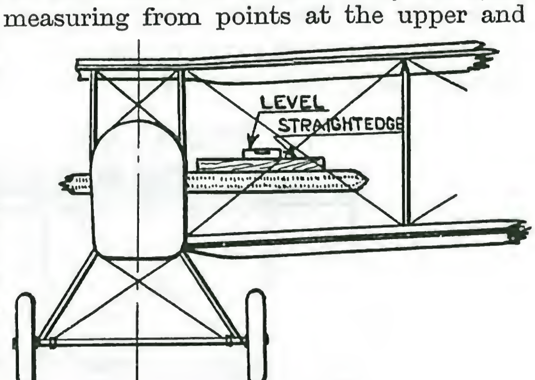

FIG. 9. TRUING UP TAIL UNIT

The rudder is checked vertically by dropping a plumb line over each side. Pack out against the top rib and measure between the line and the lower trailing edge of the rudder. The longitudinal centre line of the fin may coincide with the centre line of the aircraft, or be offset to right or left to give slight rudder effect. This must be checked to the dimension or angle given in the maker's handbook.

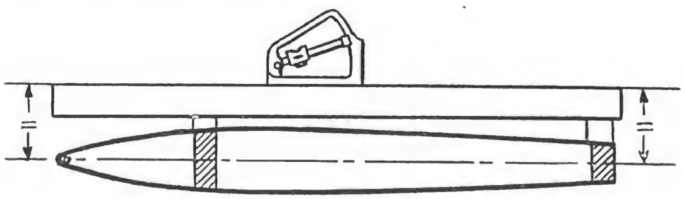

FIG. 10. MEASURING TAIL PLANE INCIDENCE

2. CONTROLS: ADJUSTMENT AND CHECK

General

The safety of an aircraft in flight is directly dependent upon the correct and adequate functioning of its flying controls. Every precaution must, therefore, be taken by the inspector to ensure the correctness of each element forming part of such a system, in addition to ensuring the adequacy of its installation, functioning, and range of operation. As meticulous care is essential and no individual infallible, the duplication of final inspection called for hereunder must not, in any circumstance, be departed from.

Control Assembly

The inspection of all aircraft controls must be duplicated, first as an operation during assembly of the aircraft, and, secondly, as part of the inspection immediately preceding flight. These two stages of inspection may not, in any circumstances, be carried out by the same individual.

IMPORTANT. It must be clearly realized that such duplicate inspection must be carried out invariably after all adjustments have been made. Not only has the functioning to be checked, but each separate control must be followed through from end to end and a careful examination made of all joints, junctions, and locking devices. If dismantling or any further adjustment of the controls is carried out thereafter, the duplicate inspection must be repeated.

Flying Controls

An aeroplane is controlled by means of the following control surfaces—Ailerons, Elevators, Rudders.

The Ailerons control the aeroplane laterally, or, in other words, they tend to make the aeroplane rotate round the axis of the fuselage (or hull in the case of a flying boat).

If the control stick is moved to the right or the pilot's control wheel turned to the right, the right ailerons must come *up*, and correspondingly the left ailerons go *down*.

The effect of this is to decrease the lift on the right planes and to increase that on the left planes, with the result that the machine banks to the right. Similarly, if the stick is pushed or the wheel turned to the left, the machine banks to the left.

The Elevators control the fore and aft movements of the machine, that is, they move the machine in a path at right angles to the planes. If the machine is flying level, and the pilot's control column is pulled back, the elevators are raised, the tail drops, and the nose rises. If the pilot's control column is pushed forward, the elevators go down, the tail rises, and the nose drops.

The Rudder (or rudders) swings the machine along a path parallel with that of the main planes. If the right rudder-bar or rudder pedal is pressed forward, the rudder moves to the right, the tail swings to the left, and the nose of the machine swings to the right. If the left rudder-bar or rudder pedal is pressed forward, the rudder moves to the left, the tail swings to the right and the nose of the machine swings to the left.

Variable Tail Plane

The tail incidence is usually operated by means of a hand wheel or sometimes a lever in the pilot's cockpit, and to increase the incidence of the tail plane the top rim of the hand wheel is pushed forward, the incidence is decreased by winding the wheel backwards. The directional control of this unit is similar to the elevator control.

Flying Controls—Adjustment and Check

After assembling the aerofoils and coupling up the controls, adjustments should be made so that the cables and other parts are fairly taut, but work without undue stiffness. All control cables, chains, rods, and levers should be carefully inspected to ascertain that these parts are in good condition and bear evidence of prior approval, and that all unions, joints, and attachments whatsoever throughout the entire system are properly and effectively locked. The flying control systems of modern aircraft are usually operated by means of extra flexible stranded cable of 7×19 construction, there being seven strands each containing nineteen wires.

It is often necessary to fit new cables, and care must be taken that the splicing is in accordance with standard requirements. When a splice is made round a thimble the cable must be gripped tightly by means of a temporary serving; $4\frac{1}{2}$ tucks are required, the splices are whipped with waxed thread. On marine aircraft the whipping is carried further up the splice than on landplanes to prevent ingress of sea water and deter corrosion. The waxed cord must be removed from time to time to allow thorough inspection of the splice. After splicing, all cables must be stretched by applying a tensile load of 50 per cent of the breaking load of the cable.

When roller chains form part of the flying control system they must be of an approved type, and should it become necessary to replace any parts or attachment fittings, the complete chain unit must be proof loaded to one-third of the ultimate load specified by the aircraft manufacturers.

Ailerons

In order to allow for the stretch of the cables when under load, ailerons are sometimes given an initial droop, the trailing edge of the aileron being set below the trailing edge of the wing. This droop is the measured difference between the trailing edge line of the wing and the trailing edge line of the aileron. Care must be taken to ensure that the control column is central when checking the amount of aileron droop; similarly the control column must always be central when adjusting the ailerons (the column is not always fore-and-aft vertical, for on some types of aircraft it is set forward of the vertical position, while on others it may be set aft).

The maker's handbook or control system diagram must be carefully studied when making adjustments; this matter is very important and applies to all flying controls. Limits of travels must be checked, and it is advisable to record the measurements in a simple form (see Fig. 11). Particular care is necessary when the balanced or Frise type ailerons are fitted, to ensure that the maximum travel is not exceeded. All control pulleys must be in proper alignment. Guards must be quite clear but must be close enough to prevent the cables riding off the pulleys or the chains off the sprockets. Chains and sprocket teeth, and sprocket and pulley bearings, must be kept clean and lubricated. The control wires or

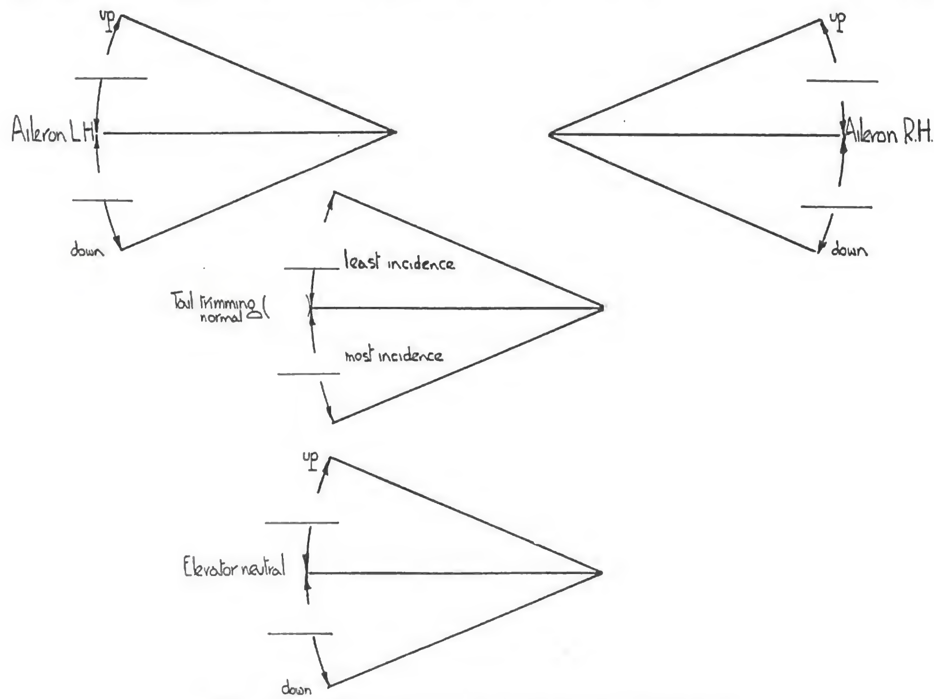

FIG. 11. MOVEMENTS OF CONTROL SURFACES

cables must not be unduly slack; at the same time they should not be over-tight, but should work smoothly throughout the whole of their run. It is advisable during the course of inspection to have the control column and the rudder bar held while an attempt is made to move the various control surfaces, due care being exercised as to the degree of load imposed and as to how and where the individual surfaces are grasped during this test.

ELEVATORS

When checking the elevators the control column must be central transversely; it is not, however, always required to be vertical as viewed in side elevation, and this fact must be carefully noted by the rigger, who must observe the instructions on the maker's rigging diagram. It is essential that the tail plane incidence be adjusted to normal position and the elevators set in a continuous line with the tail plane. After correct tensioning of the control wires or cables the elevator must be tested for functioning at all tail plane settings, and at the same time the rudders should be operated to make certain that they do not foul the elevators. The control

column's forward stop must be set to allow the correct amount of downward travel, but care must be taken to ensure that corners of the elevator spars do not come in contact with the tail plane rear spar. The travels of the elevator must be strictly in accordance with the design requirements.

RUDDER

When adjusting the rudder controls, care must be taken that the rudder bar or rudder pedals are set at right angles to the fore and aft line of the aircraft, the rudder being central and vertical. The rudder stops must be positioned to allow the correct travel. The rudder controls should just be taut and should work smoothly throughout their run.

TAIL TRIMMING GEAR

It is very important to check the normal incidence, and at the same time to make certain that the indicator position synchronizes. This should again be checked at the maximum upward and downward positions.

The run of controls must be carefully inspected and directional functioning tested after any adjustments have been carried out.

3. CORRECTION OF FAULTS EXPERIENCED IN FLIGHT

(i) Tendency to fly one wing low.
(ii) When an aircraft does not fly straight.
(iii) Nose or tail heavy.

(i) Tendency to Fly One Wing Low

If an aircraft is reported by the pilot to be flying right wing low, it may be due to the following—

(*a*) Incidence on the left wing greater than on the right wing, thus increasing the lift on the left wing.

(*b*) Ailerons warped or out of alignment when the control column is central.

(*c*) Dihedral greater on one side than the other.

(*d*) The wings becoming distorted.

(*e*) Unequal loading.

(*f*) Tail plane out of alignment laterally.

CHECK (*a*)

By placing the aircraft in rigging position and testing the angle of incidence on each wing. Should it be found that the angle of incidence is less than it should be on the right wing, adjust it to the correct setting. If the incidence is more than it should be on the left wing, decrease the same to maker's rigging diagram requirements. It may happen that the wing incidence is correct in which case—

CHECK (*b*)

If the ailerons are not in trim due, say, to stretch or slackness of cable, adjust to standard for type. If warped, aileron should be changed, or droop adjusted to compensate. Take care that this does not cause drag and result in giving the aircraft turning tendency.

CHECK (*c*)

The dihedral angles on each wing should be checked and adjusted if necessary.

CHECK (*d*)

Try with straight-edge wherever possible in way of spars, and also compare incidence readings on numerous similar places on each plane.

Distortion may be due to overtight bracings; if it persists when wires are entirely slacked off, wing must be removed and opened up for investigation.

CHECK (*e*)

This may be due, say, to unequal fuel consumption, or, in a seaplane, to water in a float: the remedy in either example being self-evident.

CHECK (*f*) and, if out of alignment, correct.

A test flight should be carried out when everything has been corrected; should the pilot still report that the aircraft is flying right wing low, give more incidence on the right wing and slightly decrease the incidence on the left wing (both, of course, towards the tips known respectively as "wash-in" and "wash-out.")

(ii) When an Aircraft Does Not Fly Straight

This may be due to the fin not being in the correct position, which gives the effect of slight rudder. Rubber cord, or a spring in the rudder control system, is sometimes fitted to counteract this defect, and if such or any other device is fitted it must be carefully inspected and treated as part of the flying control system. It must be understood that no alterations beyond the normal adjustment of such a loading device as mentioned can be authorized to correct this error, unless the Ground Engineer is notified through official channels.

An aircraft carrying rudder gives the impression of flying one wing low. When an aircraft is reported to be flying one wing low and carrying rudder at the same time it is advisable to counteract the turning tendency by adjustments and test flight before giving "wash-in" or "wash-out" to the planes, provided the aircraft was flying in a normal manner previously. Alternatively, holding one wing up will cause drag in that side and cause the aircraft to turn in that direction.

The degree of offset (to counteract torque) of the engine may be incorrect; an engine licensee must be called to correct any such error. In the case of a pusher aircraft having the airscrew close to the fin, the fitting of a new airscrew of different pitch having more or less r.p.m. than the previous one and causing the slipstream swirl to impinge on a different point on the fin may upset the directional stability; such a condition may be counteracted in the manner mentioned above.

(iii) Nose or Tail Heavy

This defect may be caused through—

(*a*) Incorrect stagger.
(*b*) Incorrect incidence of tail plane.
(*c*) Incorrect incidence of main planes (although both sides may be equal).
(*d*) Incorrect loading of the aircraft.
(*e*) Distortion of fuselage or hull.
(*f*) Water in the hull, main floats, or tail plane. (Seaplanes.)

Place the aircraft in rigging position, check and correct where necessary (*a*) (*b*), (*c*), and (*e*). Regarding fault (*d*) great care must always be taken when loading an aircraft that the C.G. limits are strictly observed.

(*f*) Drain all floats, tail plane and elevators and see that the eyelets in the two latter are clear.

Where fixed servo flaps are fitted to control surfaces, flying errors may often be corrected by "setting" such flaps *away* from the direction of the dip or turn.

CHAPTER II

4. TIMBER—DEFECTS AND DETERIORATION

Wood is not used to a great extent on modern aircraft; there are still, however, numbers of light aircraft of composite construction, i.e. wood, fabric, and metal. Structures made of timber are very much affected by extremes of atmospheric conditions. All timber used in aircraft construction is very carefully selected, therefore the defects dealt with below are those which develop after the aircraft has been in service.

Timbers commonly used are silver spruce, ash, walnut, mahogany, and plywood. Silver spruce is the most widely used for aircraft construction. Ash is used for engine bearers and fuselage struts, tail struts, etc., and walnut for airscrews and packing blocks. Mahogany is used for the construction of hulls, floats, and airscrews. Plywood, usually birch, is used for fairings, sides of box spars, walk-ways, rib webs, covering of the leading edge of wings, tail units, and on flying boats for top surfaces of wings and centre sections.

Defects

The most serious defects are: (*a*) brittleness, (*b*) compression shakes, (*c*) shrinkage, (*d*) oil soakage, (*e*) water soakage, (*f*) crushing, (*g*) (plywood) sagging, and ply separation.

Brittleness

Wooden parts become brittle due to the moisture drying out and shrinkage occurring. It is very difficult to detect this serious defect without destroying the part suspected, but if the shrinking is such as to cause slackness of metal fittings it should be reported to the makers or to a Ground Engineer licensed in Category "B" for guidance.

Compression Shakes

Wooden aircraft structures can absorb vibrations and minor shocks without serious damage, but under large shock loads such as heavy one-wheel, tail, or wing tip landings, compression shakes may be found in the longerons and main wing spars. Only the most careful inspection will reveal the presence of this kind of shake, and an indication is often given by the fracture having caused the varnish to crack across the fibres of the wooden member (see Fig. 12).

Shrinkage

Shrinkage in timber occurs if the conditions are too dry, resulting in the breaking down of glued joints and slackness of metal fittings. This may obtain particularly on component parts that have been stored for any considerable period.

Oil Soakage

Engine bearers and other timber parts near to the engines and oil tank must be carefully cleaned, and protective coatings should be maintained to prevent the wood from becoming oil soaked. It may be necessary from

time to time to scrape parts lightly and re-varnish; if the oil has soaked below the surface the strength of affected parts will be impaired.

Water Soakage

When fitting new struts, etc., great care must be taken that, after shaping, ends are treated with an approved protective coating of varnish or paint, otherwise the timber may become water-soaked and develop blue-stain, a defect to which silver spruce is very subject; this is sometimes on the surface only, but in its more advanced stage it pene. trates very deeply and is the first stage of rot.

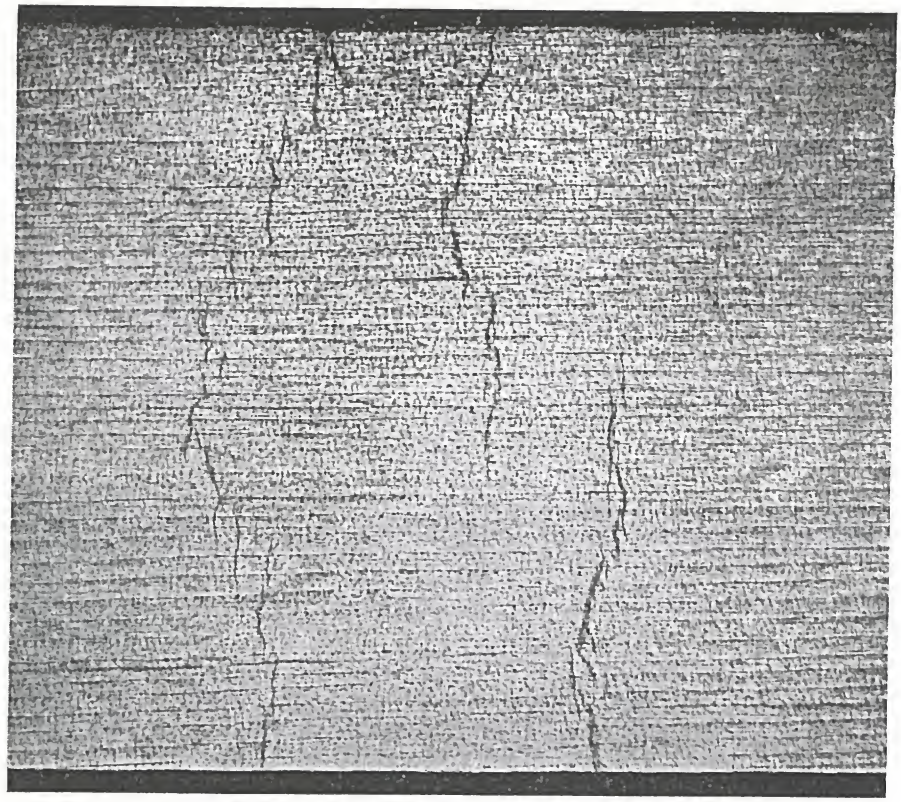

FIG. 12. TIMBER COMPRESSION SHAKE

Crushing

Wood parts are crushed by the overtightening of metal fittings and incorrect tensioning of bracing wires. The most serious form of crushing is usually caused through bad landings, and this can only be discovered by means of careful and systematic inspection.

Sagging and Ply Separation

The individual veneers of plywood sometimes become non-adherent. Plywood often sags; the timber itself sometimes loses its moisture and becomes brittle. Plywood parts should always be well protected, particularly around the edges, with liberal coatings of paint, enamel, varnish, marine glue, or other suitable protective material.

5. METALS: DEFECTS AND DETERIORATION

All metallic materials used for aeroplane construction are carefully listed and inspected, and also suitably protected against corrosion before the parts are finally passed out from the makers. Most of the subsequent defects and deteriorations can be said to be due to corrosion. In light alloys corrosion is usually in two forms—

(*a*) External.
(*b*) Intercrystalline.

(*a*) External Corrosion

As very light sections of materials are used in aircraft construction, corrosion will soon weaken the structure, and cause failure. Careful and systematic inspection must be carried out in order to arrest corrosion in its early stages. Fortunately most instances of corrosion are on the surface, and although this kind of corrosion is not very dangerous, being visible by the formation of a white powder (aluminium oxide), it may be liable to form pits and/or cavities. If this pitting is not very deep it can be removed carefully by using a soft scraper and stiff brush; the parts should then be immediately treated with lanoline or protective coatings similar to those used on other parts of the aircraft. If it is found after removing corrosion on fittings that the corrosion is deep enough to cause weakness the fitting must be rejected. In the case of steel plates the bad place may be removed and replaced by a suitable patch.

(*b*) Intercrystalline Corrosion

Corrosion in this form is extremely dangerous, there being no white powder as in the case of surface corrosion. The only signs are surface

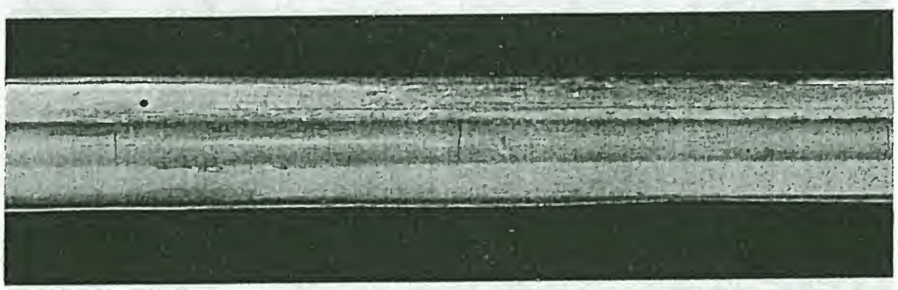

FIG. 13. DURALUMIN—INTERCRYSTALLINE CORROSION

cracks, which are sometimes very small and can only be detected with the most careful examination (see Fig. 13).

These intercrystalline corrosion cracks do not frequently occur, but should be watched for, and however fine or small the crack the part must be immediately rejected. This form of corrosion attacks the crystal boundaries inside the metal, making it weak and brittle. Alclad need not be rejected until about 75 per cent of the aluminium covering (which is about 10 per cent of the total plate thickness) has corroded away, as no pitting of the duralumin is likely until then.

Mild Steel

There is not much likelihood of cracks developing in this type of material, therefore the chief defect is again surface corrosion. This can

easily be seen because of the rust, which must be removed as early as possible. After cleaning, re-paint. The ground engineer should watch most carefully for corrosion of fittings and tubing at the welds.

FIG. 14. STAINLESS STEEL—INTERCRYSTALLINE CORROSION

Stainless Steels

These sometimes show signs of surface corrosion in the form of a reddish stain, but this can easily be removed, and the polished surface restored. Cracks may develop due to intercrystalline corrosion (see Fig. 14).

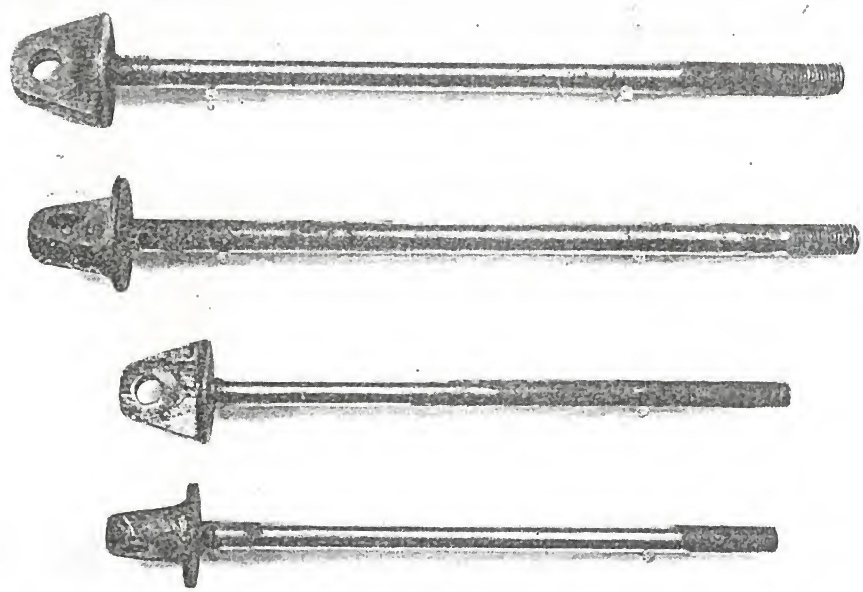

FIG. 15. STAINLESS STEEL—CORROSION

Stainless steels when in contact with wood, particularly in sea-going aircraft, should be frequently examined, as this may cause corrosion as in the case of the bolts shown in Fig. 15.

Of course, defects may be due to a combination of causes, for example, the combined effects of high stress and corrosion are well illustrated by the two photographs, Fig. 16 and Fig. 17. These cracks occurred in service in spars made from high-tensile stainless steel, and it should be noted that although they were primarily caused by corrosion, only very slight external evidence is present. It is unlikely that such cracks will be met with under normal conditions, but a careful examination of all components, from whatever material made, is obviously necessary when it is seen, as here, that such failures can occur.

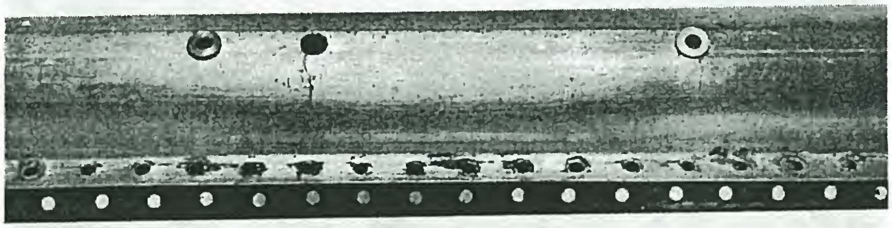

FIG. 16. STRESS AND CORROSION CRACKS IN HIGH-TENSILE STAINLESS STEEL SPAR FLANGE

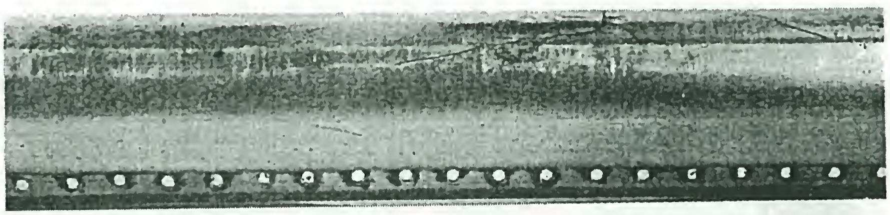

FIG. 17. STRESS AND CORROSION CRACKS IN HIGH-TENSILE STEEL SPAR FLANGE

Special Steels

Axle tubes (nickel chrome) may crack in service due to corrosion. These cracks are very difficult to detect; should there be any doubt the axle should be saturated with paraffin, and the suspected part afterwards dried and coated with whitening. If the axle is cracked the paraffin will percolate through the whitening in the region of the defect.

Copper Alloys

These are liable to surface corrosion (known as verdigris). Copper pipes may harden and crack or split where the ends have been bell-mouthed. Copper pipes should be annealed periodically at a temperature of from 600° C. to 700° C., and water quenched to re-soften.

Contact Corrosion

When two dissimilar metals are in contact, e.g. steel and duralumin, galvanic action which accelerates corrosion is set up between the metals. Great care should be taken during examination, as corrosion is very liable to exist, especially underneath fittings.

Streamline Bracing Wires and Tie Rods

Owing to the fact that bracing wires are very highly stressed in service and are manufactured from special high-tensile steel, great care should be

exercised in their inspection. The most probable causes of failure of these components are—

1. Corrosion.
2. Chafing at intersections.
3. Damage during refitting.

The following points should be carefully noted—

Corrosion

Before the bracing wires are fitted by the aircraft manufacturers they are coated electrolytically with metallic zinc or cadmium as a protective.

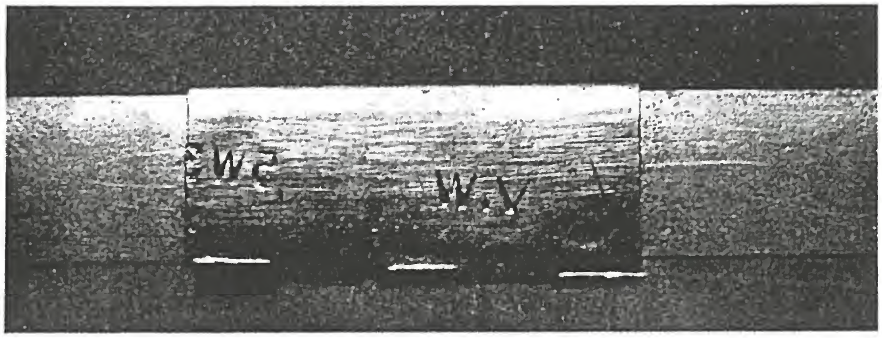

Fig. 18. Bracing Wire with Clip in Place

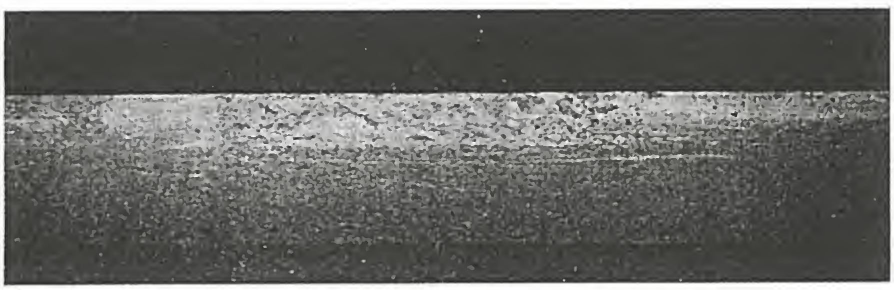

Fig. 19. Clip Removed Revealing Badly Corroded Area Beneath

This coating is extremely thin (0.0005 in.) and great care should therefore be taken when fitting or adjusting such wires to avoid damaging this coating. On no account should emery cloth or any abrasive be used for cleaning purposes.

Corrosion is likely to appear after considerable periods of service in the form of rust spots which have penetrated the coating. These should be carefully removed by rubbing locally with a brush. The wire should be replaced if the metal is at all pitted underneath the rust. If, however, no pitting is visible the wires may be coated with grease or paint before further service.

The identification clips used on streamline wires are particularly liable to cause corrosion, being made from a metal dissimilar to that used for the wires. It is therefore most important that the clip be moved along the wire and that the portion hidden by it be carefully examined. Figs. 18 and 19 illustrate clearly the necessity for this precaution. If these clips are broken they must not be re-soldered as the necessary heat may impair the temper of the steel. Particulars given on damaged clips should be recorded in the log book, no new clips being fitted.

Chafing

The points of intersection of cross bracing wires are very important, as it is here that damage may be caused by the two wires rubbing together. Even a very small indentation on a streamline wire is dangerous, as the stress becomes concentrated at this point and may cause fracture.

The "acorns," fibre discs, etc., used at intersections should therefore receive careful attention, and if damaged must be at once replaced. Chafed wires must also be replaced and great care taken in their reassembly. The wires should also be examined for small cracks, particularly if they have had a long period of service or if they have been subjected to heavy vibration.

Refitting

When refitting or replacing a wire, the condition of the wiring plate holes and the correct alignment of the lugs should be checked. The fork ends and pins of the wire should be examined. When adjusting the length, and in order to avoid damage to the protective coating and the edges of the wire, a special spanner should be used. The lock nuts used must be of brass or cast iron so that if they are overtightened they will not damage the thread of the wire. The correct minimum amount of thread must be in engagement, as indicated by the wire reaching the small hole drilled in the fork end.

General

Careful watching and systematic inspection are always necessary to check corrosion in the early stages.

All open ended metal tubes must be inspected internally, as, although the external condition may be good, failures can occur due to internal corrosion.

6. OTHER MATERIALS

Fabric Covering

The fabric, sewing thread, and braided cord normally used for coverings and attaching the fabric to the ribs, are of the best quality linen. These materials must be carefully stored and the fabric should be kept in a room of fairly high temperature, 70° F. being suitable. This will ensure the evaporation of all moisture which would prevent satisfactory doping. Prolonged exposure to strong daylight is injurious to fabric.

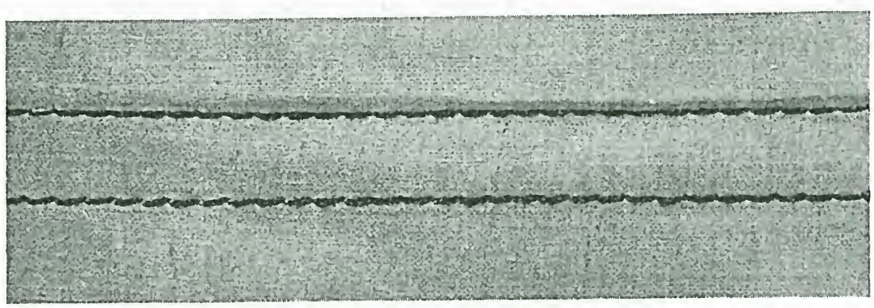

Fig. 20. Fabric Width to Width Seam

Repair Work

To enable the repairs to fabric coverings to be carried out in a satisfactory manner, it will be necessary for the ground engineer to have a thorough

knowledge of wing covering, sewing operations, and the attachment of fabric to the ribs. These operations are very important, and every effort should be made to restore the damaged coverings as nearly as possible to their original strength and condition. The materials used on the aircraft undergoing repairs must be similar to those already used, and previous methods must be closely followed. The following notes are intended as a general guide. The type of seam used for joining fabric is the double balloon seam, and must be made as indicated in Figs. 20 and 21.

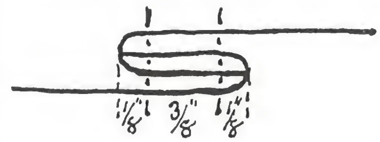

Fig. 21. Cross Section of Seam

The machined seams should have approximately nine stitches per

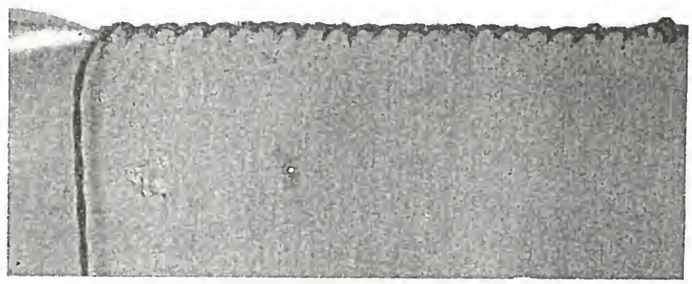
Fig. 22. Fabric Envelope Edge Sewn—Stitches Knotted

inch, using single 40's linen thread. Hand-sewn seams are lock-stitched eight stitches per inch and double-locked every 6 in., using single 18's or double 40's waxed linen thread (see Figs. 22 and 23).

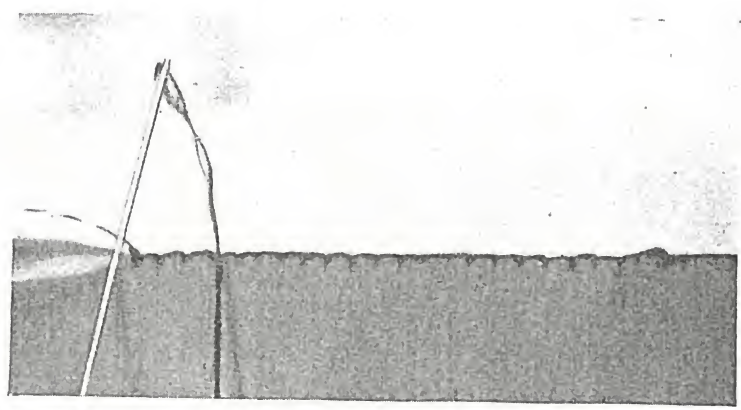
Fig. 23. Fabric Envelope—Edge Sewing and Thread Knotting

The fabric is secured to the component by stringing to the ribs (Egyptian tape between) with braided waxed cord. The pitch of the stitches is 3 in., each stitch being knotted and doubly knotted at every 18 in. (see Figs. 24, 25, 26, and 28).

Special precautions must be taken when attaching the fabric in the region of the airscrew slipstream. For aircraft fitted with engines of 400 h.p. and over, the pitch of the stringing is reduced to $1\frac{1}{2}$ in. (see Fig. 27).

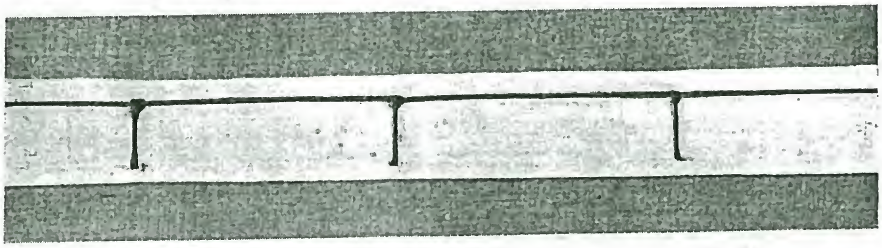

FIG. 24. FABRIC STRUNG (SHOWING KNOTTED SIDE) TO RIB

All stringing of ribs, and sewing threads around the trailing edge and/or end box ribs, must be protected by doping on serrated or frayed-edge tape (Figs. 29, 30, 31, 32, and 33).

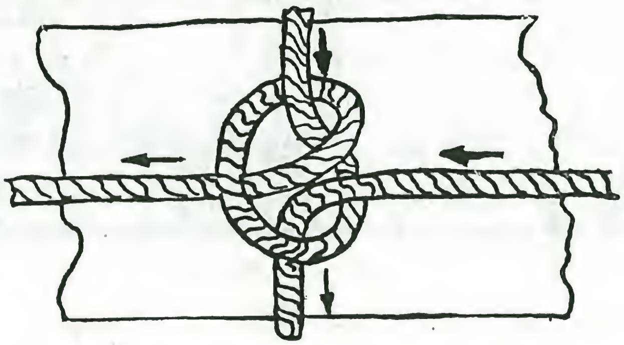

FIG. 25. RIB STRINGING, DETAIL OF KNOT

All repairs should be carried out as detailed above unless otherwise stated in the aircraft maker's approved handbook. If large sections of fabric need replacing, the new fabric, after joining to the remaining

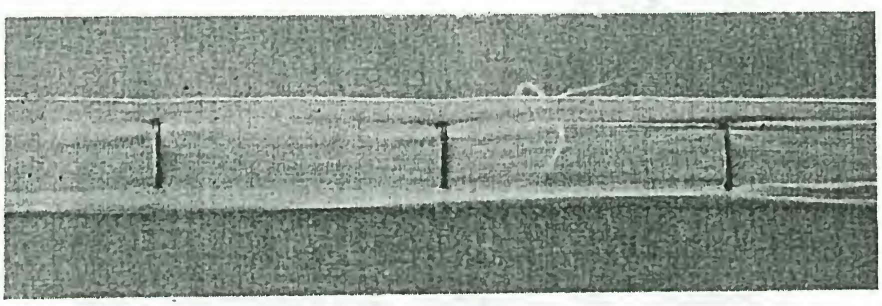

FIG. 26. FABRIC STRUNG (OPEN PITCH) TO RIB

original fabric, should be drawn tight when sewing, and the tension must be uniform over the new area. Care must be taken not to overtighten the fabric on light structures as the additional tightening by doping may cause distortion. When repairing a small tear in the fabric, first remove

the dope around the damaged portion by the use of an approved dope solvent, or by peeling the old dope away, afterwards sewing the edges

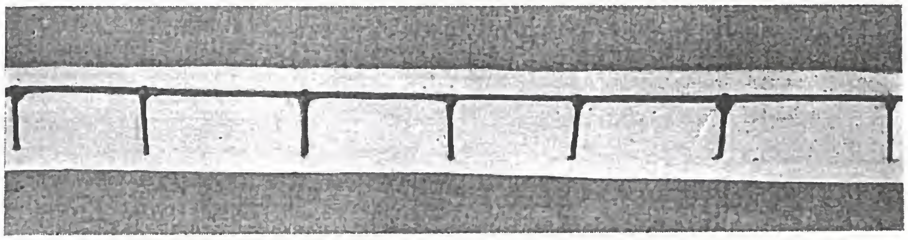

FIG. 27. FABRIC STRUNG (CLOSE 'SLIPSTREAM' PITCH) TO RIB

together and doping on a suitable frayed fabric patch, then covering with the necessary coats of dope as called for under the scheme. Where the fabric

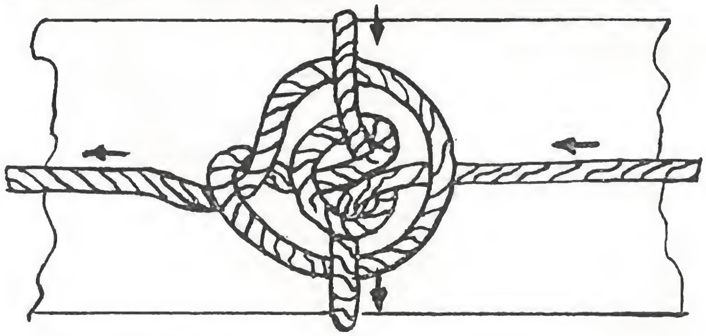

FIG. 28. RIB STRINGING, DETAIL OF DOUBLE KNOT

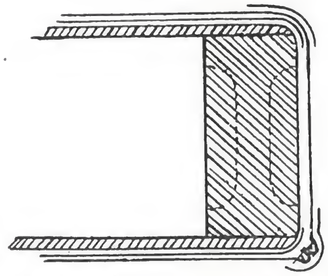

FIG. 29. METHOD OF ATTACHING FABRIC TO REAR SPAR

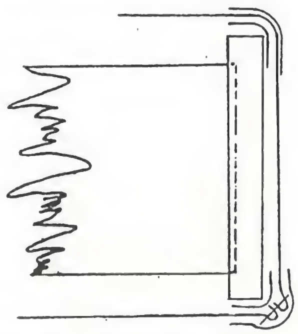

FIG. 30. METHOD OF ATTACHING FABRIC AT END RIB

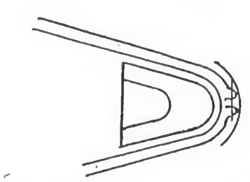

FIG. 31. METHOD OF ATTACHING FABRIC AT LEADING OR TRAILING EDGES

FIG. 32. FRAYED-EDGE TAPE (ALTERNATIVELY, MAY BE SERRATED)

is badly torn the jagged edges should be cut away to a square or oblong shape and a piece of fabric of similar shape inserted, sewn in, and the repair finished as already described. Holes and tears in the coverings must be repaired immediately, as they may rapidly extend by tearing in the wind and the effect may further bring about alteration of the static pressure within the wing, which in turn might increase the normal rib

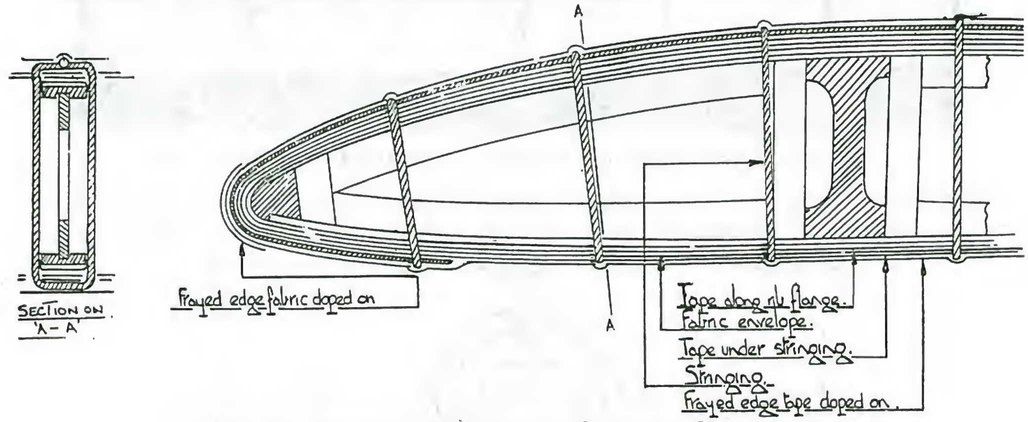

Fig. 33. Section of Finished Covered Component
(R.A.F. Official Crown Copyright Reserved.)

loading. The maintenance of fabric coverings is a very important item both for the safety and efficiency of the aircraft.

Doping of Fabric

Aircraft dopes are of two kinds: (*a*) acetate dopes; (*b*) nitro dopes. There are several approved proprietary doping schemes, and the makers of these schemes issue instructions for use, which must be followed. The complete doping of fabric-covered components is a method of producing and maintaining a taut, waterproof and airproof surface; it is a protective covering for the fabric. It prevents deterioration of the fabric by light, weather, and service conditions. Pigment is added to dope to protect the fabric from light rays, but as pigments absorb heat a final coat of aluminium is sometimes given in order to reflect the heat rays.

General Application Conditions

A fairly stiff brush should be employed, of which the bristles must be secured by rivets to avoid loosening by the solvents in the dope. The first coat of dope, which must not be thinned, should be well brushed into the fabric with sufficient pressure to ensure thorough impregnation. Further coats of dope may be brushed or sprayed in accordance with the approved proprietary scheme, which should also be the guide for between-coat intervals, number of coats, etc.

Atmospheric Conditions (doping scheme for workshops)

Doping should be carried out in a warm dry shop with a temperature of not less than 60° to 70° F., free from draughts, but having efficient ventilation. Moisture in the atmosphere should be kept at a minimum and the relative humidity should not exceed 80 per cent.

Doping Under Adverse Conditions

Doping schemes for repair or renovation of machines under aerodrome or unheated shop conditions permit doping to be done in the open air.

A sheltered place should be selected where strong draughts and gusts of wind are reduced to a minimum. The weather should be warm and dry; doping should never be done if the temperature drops below 32° F.

General Precautions

There is a tendency for the pigment to settle out with all coloured dopes, therefore great care must be taken to ensure that the containers are thoroughly stirred and shaken before and during use. It is also very important that dope, dope covering, cleaning solutions or brush wash, etc., of one scheme are not mixed with other schemes.

Defect and Deterioration

Dope on covered components may, with continuous service, become brittle and crack. This may expose the fabric to weather, which will cause the fabric to perish unless this defect is immediately corrected. The best remedy is to remove the cracked dope film by the use of a dope solvent, thoroughly clean, and re-dope. Another defect known as soggy fabric is due to the deterioration of the dope by long exposure to varying weather conditions; this particularly applies to dope on covered components fitted to marine aircraft which are often moored out for long periods. Soggy fabric may also be caused through neglect to clean off oil, which will in time not only destroy the dope film, but penetrate to such an extent as will result in the fabric perishing, thus rendering components unserviceable. If the dope film only is defective, clean off with dope solvent and re-dope strictly in accordance with the doping scheme on the remainder of the component or components. All fabric components should be kept as clean as possible and even small defects should receive immediate attention; this will preserve the covering and assist in maintaining the performance of the aircraft. The dope film may become chafed, damaged, or punctured locally, and may split or crack; the film should be peeled or dissolved from the area immediately surrounding the damage, and the fabric repaired if necessary, the place then being re-doped as already explained. The sharp places of the component—edges, ends, blocks, rib-peaks, and the walk-ways used by the ground mechanics during their work, etc., as well as all other areas likely to become prematurely worn, should be often and carefully noted and re-coated as required.

7. AIRSCREWS

There are many different types of airscrews, but those commonly met with in British practice are of two kinds; those made of layers or "laminae" of timber (mostly all-mahogany or all-walnut) glued together, and those of metal (solid light alloy).

Both mounted and unmounted airscrews should always be very considerately housed, in clean, ventilated, even-temperatured and sheltered situations. Spare airscrews should be stored with their leading edges downwards, supported on the boss and lightly held by a support cut to shape and packed about midway along each blade. It should be always carefully noted before fitting an airscrew that it is of the correct design and type for a particular type of aircraft and engine. Its drawing number, diameter (the circle in feet described by the tips in rotation) and pitch (approximately the forward distance in feet that would be moved through at one rotation if there were no slip) are always to be found stamped on or adjacent to the boss.

Great care is necessary when fitting the engine hub to the wooden

boss of an airscrew to see that all bolts are lightly tightened at first and finally drawn up both evenly and tightly. The bolts should again be checked after the first engine run on the ground and from time to time.

During the fitting operation care must be taken not to crush the timber by overtightening.

It is necessary to check the track of the airscrew after it has been mounted and secured to the engine. To do this, place a trestle in position in front of the path of the airscrew and level with a point near to the tip. By the use of a fixed scribing block or some definite point on the trestle, measure the distance to the leading or trailing edge of each blade as it is brought round by hand. Errors may be due to incorrect tightening of the hub bolts. Various limits are laid down regarding the permissible track errors for airscrews of different diameter, and the margins stated for the manufacturer's handbook should be rigidly adhered to. The maximum error permissible to conform to A.M. requirements is $\pm$ 0·03 in. for airscrews up to 5 ft. diameter, increasing by $\pm$ 0·01 in. for every 2 ft. increase of diameter.

Damage to an airscrew may occur when the engine is running on the ground, due to small stones, etc., being drawn up. Scratches and small indentations in light alloy airscrews from this cause may be removed by a file or emery cloth, the places being made to "fade" easily and smoothly into the surrounding surfaces.

On seaplanes the protective covering becomes damaged by water spray during taxying and take off. It is essential that any damage to the cellulose lacquer should be repaired without delay. Airscrews slightly out of balance should be corrected during the re-application of protective coverings.

Airscrews are often very highly stressed units, and any small defect in timber or metal (perhaps unnoticed during manufacture) may quickly develop. The boss, the hub bolt holes, the root and each blade's length, should be carefully gone over for signs and splits, flaws, or fractures of any kind. Glued joints should always show continuous sound adhesion. On wooden airscrews with blades covered with fabric the latter tends to become threadbare and to fray, also the edges of the timber, particularly towards the tips, sometimes become fibrous and ragged with heavy wear. Tip cappings, tipping and edging sheaths may also become loose. Tip drain holes should always be kept clean and clear. Light alloys often corrode very rapidly in the presence of sea water or ozone-charged atmosphere (see "Material Defects and Deterioration").

With airscrews made of light alloy, therefore, and particularly those used in coastal or similar places, this trouble should be carefully looked for, not only on the exposed faces but also on all portions which are covered by any other part such as the hub and spinner, etc. Corrosion once commenced cannot satisfactorily be arrested. An airscrew so affected should be removed and a replacement fitted in its stead.

The protective coating of airscrews should always be maintained in a first-class condition. An airscrew is said to be in static balance when the centre of gravity lies at some point along the axis of rotation. A statically balanced airscrew will exert no turning moment, however it may be positioned on the mandrel of the balancing machine. An airscrew lacking static balance will always exert such a turning moment except when in such a position that the centre of gravity falls upon a vertical line passing through the axis of rotation. The turning moment is greatest when the airscrew is positioned so that the line joining the centre of gravity and axis of rotation is horizontal. For this reason, when the static balance of

an airscrew is in doubt, the balance is checked at two settings at right angles to each other.

It should be tested on a suitable approved apparatus, consisting of a ground spindle either on accurately levelled knife edges, or by two pairs of large discs mounted on ball or roller bearings; the apparatus being kept in a position free from draughts and vibration. The apparatus should be of known accuracy. The airscrew should be within the limit of 2 in.-oz. for diameters up to 6 ft., increasing by 1 in.-oz. for each 2 ft. by which the diameter exceeds 6 ft. Moisture absorption by, or any repair work on, a wooden airscrew will seriously affect balance.

Any work beyond the re-application of protective coverings involving balance is best dealt with by the makers; the suspicion that blade angles (they will be measured in the shops with the airscrews on a surface-table, at certain positions or "stations" along the blade by a protractor) or that any other distortion whatsoever has taken place should receive the maker's attention.

The closest inspection should be made for material defects, and for lack of balance and incorrect pitch angle, as any of these may quickly cause excessive vibration.

Such important members of an aircraft should always receive the close attention which is their due, for engine and structural damage and serious danger may arise from an imperfect airscrew.

Airscrews should never be handled when hot (i.e. immediately after prolonged running) and during turning operations should always be held well in toward the root, particularly the light alloy type of airscrews, as these taper so rapidly and are very thin towards the tip. (Some airscrews are marked with boundary marks beyond which the airscrew may not be handled.)

8. CONTROL MECHANISM: DEFECTS AND DETERIORATION

All hinge pins, and also pins at the control column, should be inspected for excessive wear. Examine the run of cables for fraying, paying special attention to the portions that bear on the fairleads and the attachment of the cables to control surface. Operating levers should be inspected for wear and security, and the splices and eyes for corrosion and stretching. All attachment and control rods must be carefully inspected for wear and safety; if any control rods or cables pass through components such rods or cables must be removed and examined for corrosion more frequently on the lower planes and tail units of marine aircraft than would normally be necessary for land aircraft.

It is important that the control stops do not allow movement beyond the limits laid down. The travel of all controls should be checked from time to time, the control column being set in accordance with the maker's control diagram. Careful lubrication is required at all places provided and at all hinge pins and other moving parts, which must be cleaned from time to time for examination. All chains complete with attachments must be checked for stretching, and for wear and corrosion. Throughout the whole control system it is most important to inspect the split pins for wear and corrosion; the pins must be replaced if affected. All split pins must be of correct size and length and must have a washer between them and the fitting. Having once been taken out of a fitting they must on no account be used a second time.

When replacing cables or other parts of a control unit the whole system must be examined for correct functioning and travel of control surfaces

and travel attachments, for freedom and travel throughout the control range, and for locking of all attachments. After any replacements or adjustment of flying controls the examination must be duplicated.

Examination of Slack in Aircraft Controls

Undue slackness in the control system of an aircraft is liable to cause flutter; it is important, therefore, that special attention be paid to the fit of all control bearings, which should be as free from play as possible, consistent with ease of manipulation of the controls. Any slackness at these points will be magnified by the length of the control column, levers, etc.

Control cables which pass through or over fibre fairleads are to be left dry and not greased, as the grease picks up grit and abrasive matter which accelerates the wear of the cable.

9. INSPECTION AFTER A BAD LANDING

Land Aircraft

1. Jack up under fuselage until wheels are clear of the ground.
2. Remove landing wheels and examine hubs and brakes.
3. Check undercarriage struts for straightness. Renew if bowed or damaged, and inspect all points of attachment, bolts and pins for partial shear and holes for elongation.
4. Disconnect oleo legs at lower end and check axle for alignment.
5. Remove tail wheel or skid assembly, examine for distortion and excessive play, and inspect the structure at the points of attachment and along those members of the frame through which load is distributed.
6. Set fuselage in flying position, and check all rigging dimensions.
7. Remove all inspection covers, and check internal bracing wires; if these are very slack carry out further inspection of internal fittings, spars and attachment points. Never adjust bracing wires unless the cause of slackness has been discovered.
8. Unlace fuselage bag and examine internal structure for damage to longerons, struts, fairings, and bracing wires.
9. Inspect all controls. If the aircraft is fitted with folding wings these should be tested for correct functioning, and an examination made of attachments and locking arrangements.
10. Should the wing tip come heavily in contact with the ground, or any other object, examine the points where interplane struts are attached to the wings. Carefully inspect the rear spar and aileron attachments, also the wing root fittings. If the wing fabric is puckered the component affected must be opened up and checked internally, also the spars carefully inspected for fractures, i.e. splitting, crushing, and compression shakes. It is most important that a systematic inspection be carried out after a bad landing, and to emphasize the importance of this fact it must be remembered that the load on the bottom plane spars may have been transferred by the struts and bracing wires to the upper plane spars, and by virtue of the lift wires may have given compressive stresses to those members. These stresses can again have been reduced or increased by the tension in the front, and compression on the rear spars, caused by the drag component of the force applied by meeting the ground or other obstacle. It should be realized that damage may occur in a region remote from the point of contact, especially in the locality of the wing cellule attachments and also the anchorages of points carrying concentrated loads, e.g. petrol tanks and engine mountings.

Flying Boats

Heavy drift landing may damage the wing tip floats, in which case careful inspection of the float struts and bracing wires should be carried out. The attachment fittings of the wing tip floats to the main planes should be removed so that the spars can be inspected for crushing, splitting, or compression shakes. Should there be no definite failure of the spars in this respect, check internal wing bracing wires for correct tension, and examine fittings and main wing bracing wires at points immediately above float attachment fittings, also the interplane struts and their fittings.

HEAVY TAIL LANDINGS on flying boats invariably damage the leading-edge ribs and fabric of the tail plane.

Carefully inspect the whole tail unit and test rudder and elevator control cables for signs of stretching, and the operating levers and rods for distortion and freedom of movement. Check the tail adjusting gear for functioning and the tail plane struts for bowing. The front spar of the elevator along the line of the hinge pin fittings should also be examined for failure. A very heavy "pancake" landing on the hull may result in buckling of the planing bottom and sides of the hull, and damage may occur to the frames and steps. Carefully inspect for failure of material and check wing attachment fittings on the hull, on upper and lower planes, and upper side of wing root fittings to centre section.

Carry out further inspection as for land aircraft.

10. MISCELLANEOUS GEAR

Wheel Brakes

The modern landplane is almost universally equipped with wheel brakes, enabling it to be brought quickly to a standstill on landing, giving greater ease and rapidity when manoeuvring upon the ground, permitting chocks being dispensed with during engine tests, and offering its pilot a wider choice of landing areas.

Various kinds and types of braking systems are used, the description of one (Vickers) which hereafter follows—

It is shown diagrammatically in Fig. 34. Brakes are fitted to the four wheels of the main undercarriage (a large four main-wheeled aircraft is here considered) and are operated by compressed air. The master control is a double grip hand lever mounted on the control wheel, and operation of the rudder bar in the normal way gives differential braking to assist steering on the ground. An overriding control is used to lock the brakes for "parking" and when "running up" the engines. The various components which comprise the system are as follows—

(*a*) The hand lever master control, which is mounted on the flying control wheel. Operation of this lever controls, by means of cable transmission, the relay mechanism of the main control valve, and gives braking proportional to the load applied.

(*b*) The main control valve, which is placed under the pilot's floor, is connected to the hand control and to the rudder mechanism. This control is in effect a duplex relay valve and whilst the hand control actuates both valves equally, and gives compensated braking, the action of the rudder bar causes an increase of braking on one side and reduction on the other.

(*c*) The parking control, which is mounted on the engine throttle control box, operates the main control valve by means of a cable wire transmission and provides an overriding control which applies all brakes.

(*d*) The duplex pressure gauge on the dashboard is connected to the

main control valve and gives indication of the pressure existing in the line to the brake motors.

(*e*) The wheel brake units each consist of a simple, cam-operated, two-shoe brake of automobile type. The cam is operated by an external air motor, and the whole is mounted on a torque plate.

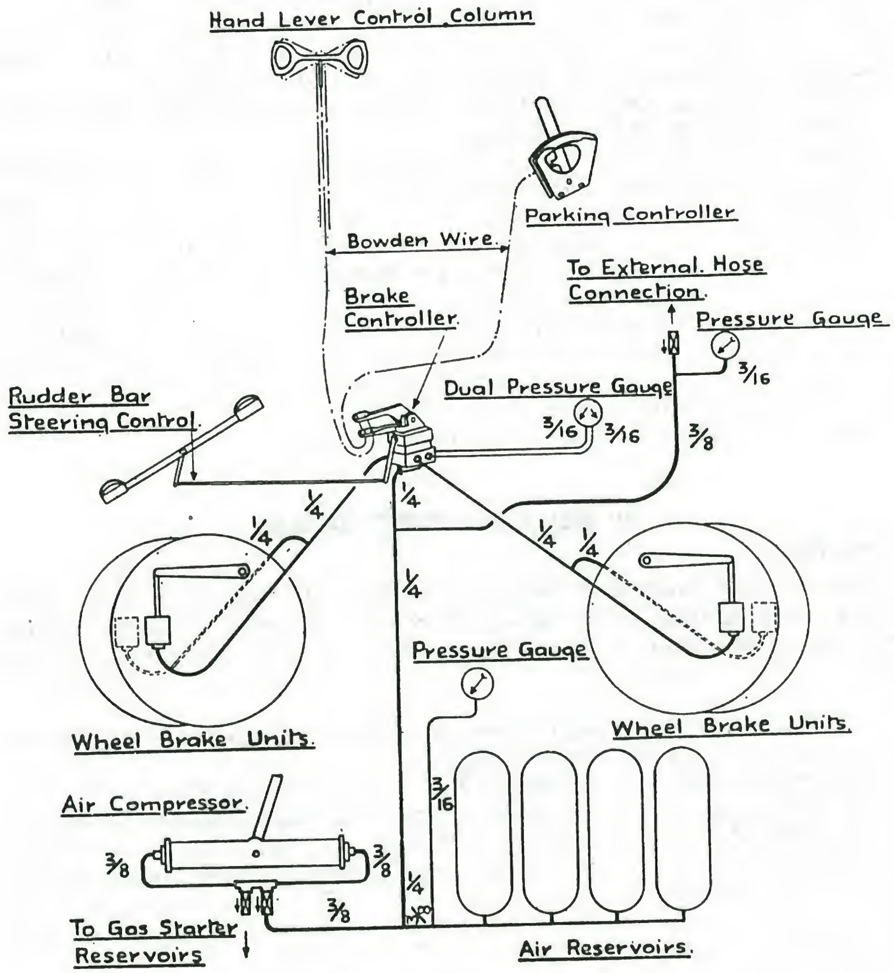

FIG. 34. BRAKE DIAGRAM

(*f*) The metal air storage reservoirs (unreinforced non-metallic reservoirs are not permitted), four in number, are fitted in one of the rear compartments below the cabin floor.

(*g*) The duplex hand air compressor is fitted below the cabin floor in the reservoir compartment. The pump is operated from the cabin, access being obtained though a door in the floor.

(*h*) The complete piping system connects all parts and is shown on the diagram.

The brake system is complete in itself, but provision is made whereby the reservoirs may be filled on the ground from the external connection, which may be coupled to a gas starter.

Method of Operation

Pressure applied to the hand control levers causes the relay valve to admit pressure to the brake motors, and gives compensated braking proportional to the load applied to the hand grip. Use of the rudder bar in the normal way gives differential braking for ground manoeuvres, and the change of pressure varies with the movement of the rudder bar. The pressure indicated on the duplex gauge need only be observed when testing the brakes; the action of the brakes in use will be entirely automatic.

The "parking" control, when fully applied, gives a braking force much higher than that given by the hand grip, and should be used only when the aircraft is at rest.

Before "taking off" a glance at the pressure gauge will ensure that the brakes are definitely "off"—pressure zero.

Full braking will be obtained as long as the pressure in the reservoirs is maintained above 55 lb. per sq. in.

Maintenance

The air pressure in the reservoirs should be maintained at 200 lb. per sq. in. The hand pump in the cabin is provided so that ample pressure may be assured before landing.

Once before each flight the brakes should be tested to ensure that they are in order.

Tests

1. Ascertain that the pressure in the air reservoirs is between 180 lb. and 200 lb. per sq. in.
2. Apply brakes by hand lever—rudder bar normal. The pressures indicated on the gauge on the dashboard should then read 55–55 lb. per sq. in., or as required, depending on the particular installation.
3. Still holding hand lever on stops, move rudder bar for turn to port; pressures on gauge should now read: 75–30 lb. per sq. in.
4. Repeat above for starboard; pressure should then read 30–75 lb. per sq. in.
5. Bring rudder bar to normal, release hand lever: pressure zero.
6. Rudder bar should now be oscillated through full angle as in flight: pressure on gauge must remain at zero.
7. Pull "parking" lever to full extent and note that a pressure of 75 lb. per sq. in. is registered by both pointers. Any difference of pressure can be corrected by slight movement of the rudder bar.

If the machine is "parked" in gusty weather, the rudder control should be lashed.

In order to reduce to a minimum the amount of air used in braking, it is advisable, occasionally, to take up wear of the shoes by lengthening the adjustable screwed connection rod of the brake motor. This adjustment may be carried out while the wheel is resting on the ground, and should be such as will allow the end of the cam lever to be moved, say, 0·2 in. to 0·25 in. when the connecting rod is pulled by the hand in a direction parallel to its axis. No attempt should be made to alter the adjustment of the main control valve. This is a rather complicated mechanism, and if it ceases to function perfectly, it should be replaced by a new unit. It is very important that all joints in the air lines be kept tight.

When the aircraft is "parked" an occasional check on the pressure in the reservoirs should be made. Any serious drop in the pressure would

indicate a leak, which should be traced and rectified. When searching for air leaks, special attention should be paid to the various non-return valves which are fitted at points throughout the system, especially that nearest to the external hose connection. The brake units are fitted with oil excluders to keep oil or grease from the brakes. If at any time the braking seems defective, although the pressures are normal, it would be advisable to inspect the brake drums and shoes for oil.

When charging the air reservoirs by means of the gas starter pump, it will be obvious that DRY air and not carburetted air should be pumped in.

The hand air compressor in the cabin should receive an occasional small quantity of engine lubricating oil.

Description of Main Control Valve

The main control valve has many duties to perform, and it is essential that its method of operation be understood so that in any emergency replacement parts may be fitted and any minor adjustments carried out. This valve governs the maximum pressure which may be applied to the brakes at all times, and responds to the movements of the hand brake levers (mounted on control wheel), to the action of the rudder bar, and finally, to the "parking" control.

The valve box contains two identical groups of mechanism, one controlling the left-hand brakes and the other those on the right-hand side.

Each group consists of an inlet valve (pressure), and exhaust (release valve), a rocking plate, its associated diaphragm and governing spring. There are also the connections to the air storage reservoirs and to the brake motors.

The diaphragm is acted upon, on the one side, by the governor spring load, and on the other by the pressure existing in the brake chamber (in communication with the brake motor).

When a balance exists between these forces the pressure in the brake motors and consequently the braking force bears a direct relation to the load on the governor spring, which is directly acted upon by the hand lever. The inlet and exhaust valves are also closed, and do not open again until the state of balance above referred to is altered. If it is desired to increase the braking, the load on the governor spring is increased by the application of greater force to the hand lever. This alteration of the balance causes the diaphragms to move upwards. The exhaust (release) valve then opens and allows air from the brake motors to escape until the pressure in the brake chamber again balances the governing spring load. When the brakes are entirely released the governor spring load is zero and the exhaust (release) valve is permanently open (pressure in brake system—atmospheric). From the above it will be seen that the maximum pressure obtainable in the brake motors depends upon the movement of the lever which loads the governor spring. The movement of this lever is limited by adjustable stops. The maximum loads on the governor springs are affected by the position of the rudder bar. In the foregoing the rudder bar has been assumed to be in the normal position. Movement of the rudder bar gives increased braking on one side and reduced braking on the other by means of the rocking differential lever.

The amount by which the pressures vary on a turn depends upon the angular movement of the rocking lever, and this has been fixed in this instance.

The only parts of the complete assembly which are likely to require attention are the valve seats. Should the valves leak it is best to replace the complete unit by a spare one. The faulty control may then be examined

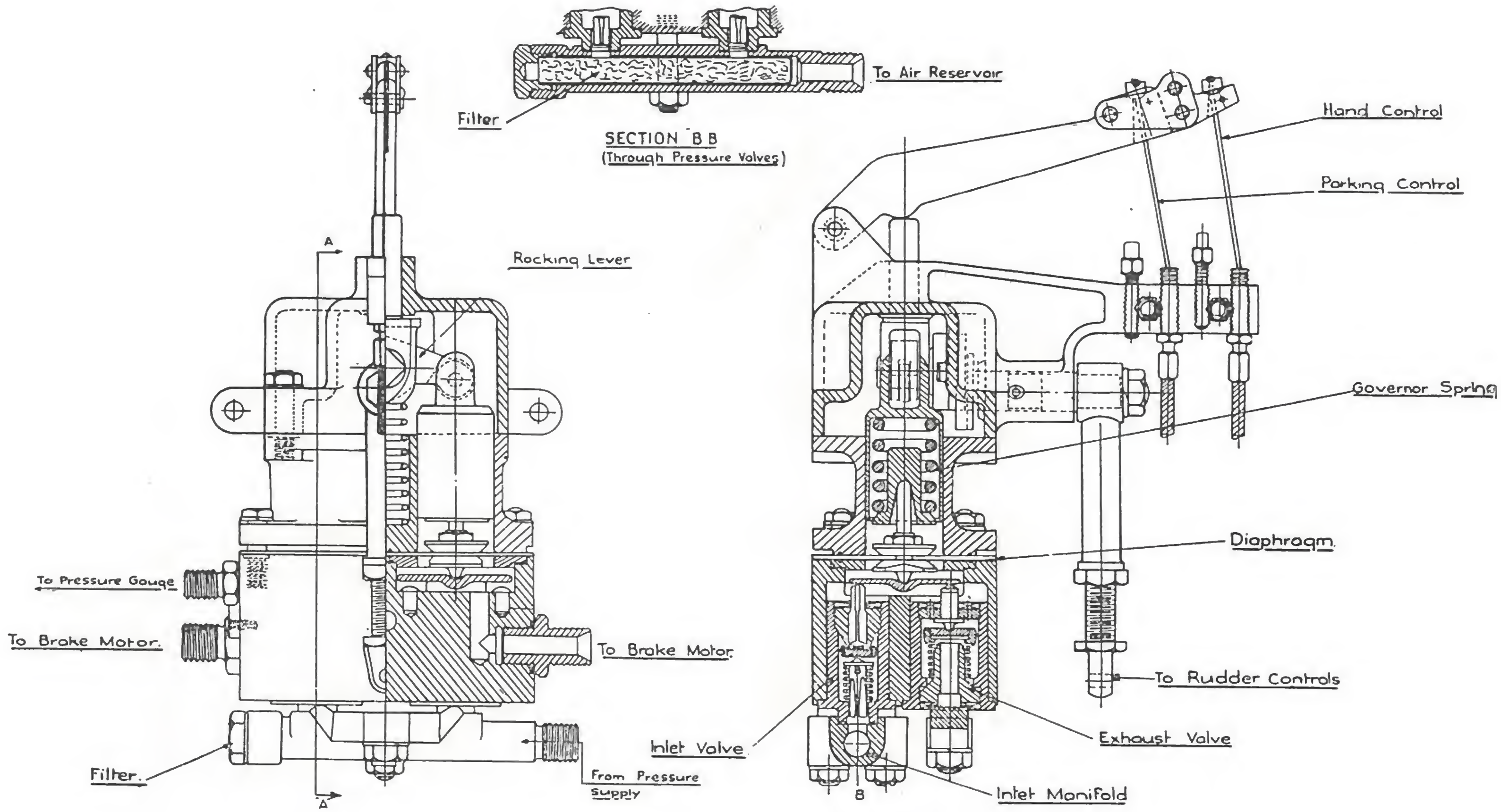

FIG. 35. BRAKE CONTROLLER

and the unit valves withdrawn and replaced by spare units. The unit valves are all made to jig and are interchangeable. Care should be taken that the replacement valves are fitted in the proper places.

In order to prevent any foreign matter getting in the valves, a horsehair filter is fitted in the pressure inlet; for cleaning (in petrol) this can readily be withdrawn by unscrewing cap.

The main control valve is shown in Fig. 35.

Brakes

Bendix brakes (see Fig. 36) consist of two shoes (primary and secondary). The primary shoe is in contact with the cam block of the

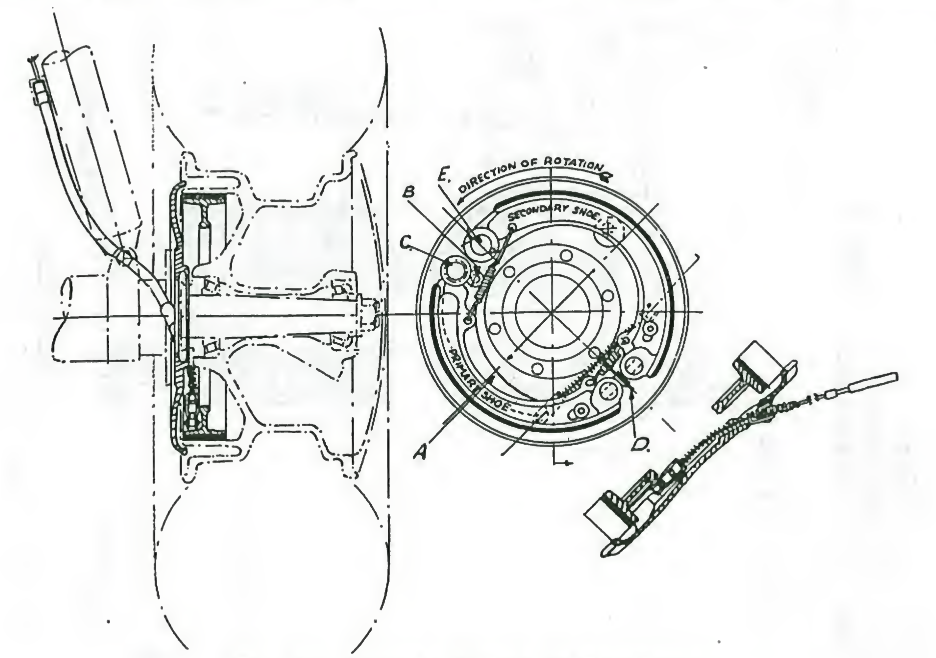

Fig. 36. Typical Brake Installation

operating lever at one end, and is hinged at the other to lower end of the secondary shoe.

The other end of the secondary shoe is anchored to the brake back plate. The hinged connection between the two shoe brakes provides a means of adjustment and consists of a turn buckle, the inner portion of which is enlarged to form a "star" wheel.

In assembling, the hand brake lever is set so that in the fully-on position the pins are centrally adjusted in the running slots. When the rudder bar is moved to the right the fin comes to the end of its travel and so puts tension on the cable running down through the radius rod to the back of the brake drums. This gives a rocking movement to an arm bearing on the toe of the primary and heel of the secondary shoe and so tends to stop the wheel.

The adjustment of this brake (see Fig. 37) is simple provided the principle is understood. It is essentially the primary shoe that gives the power to the brake and not the tension applied to the hand lever. Smooth operation of the brake is impossible with any cables that are tight, or show any tendency to tension with the hand lever in the off position.

After connecting up the cable the wheels should be put on and the cables tightened, and a deliberate load applied to the hand lever to get as much slack out of the system as possible.

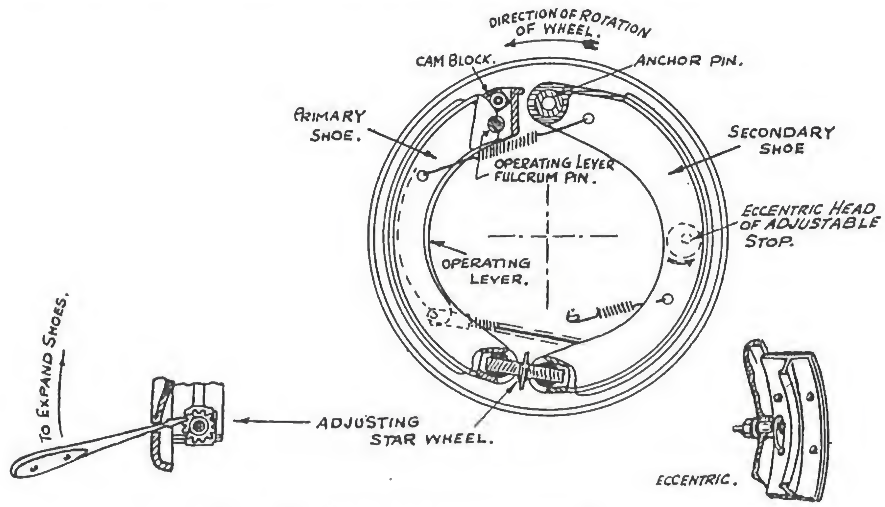

FIG. 37. BRAKE ADJUSTMENT DIAGRAM

The cables are then slackened off and the wheels removed, care being taken to leave the shoes in the centralized position. Now slacken or tighten the cables by means of the turn buckles, so that the cam between the toe of the primary and heel of the secondary shoe is free to shake.

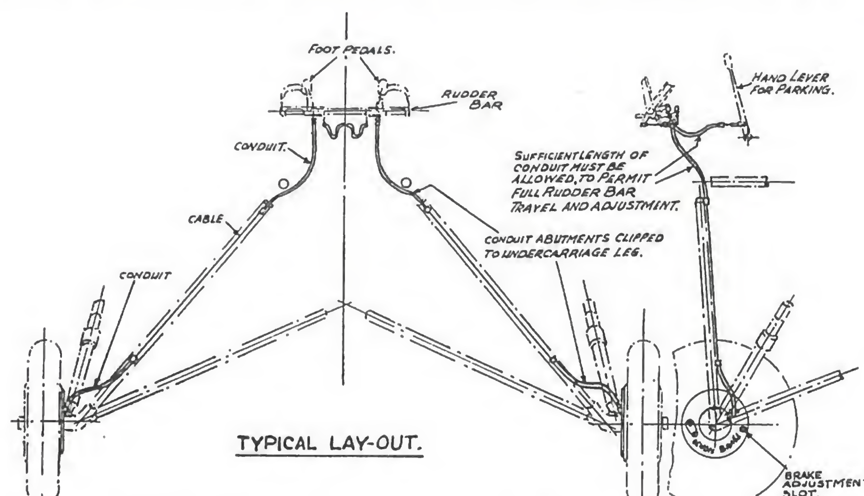

FIG. 38. TYPICAL BRAKE SYSTEM LAY-OUT

This adjustment is absolutely essential: practically all trouble with this type of brake originates in maladjustment here.

The wheel can now be put on and finally adjusted with the star wheel.

In assembling the brake, care should be taken to see that the star wheel is not assembled in the reverse position, which is quite possible. The

effect of this is to confuse the operator when the machine goes into service. The standard adjustment to tighten this brake is to move the handle of the screw-driver inwards and towards the axle. If this star wheel is reversed the shoe will be drawn in instead of expanded.

It is important to take up shoe wear only on the star wheel and *never* on the cables.

Shock Absorbing Devices

A perfect landing would be one where the stresses existing in an aircraft passing wholly through the air totally changed to those existent when it is wholly at rest on the ground, in a smooth, gradual, and evenly progressive manner, without any fluctuating reaction whatsoever.

Actually, no perfect landing (or take off either) ever occurs. The first contact of an alighting aircraft with the land or water, and the landing and departing runs over rough, broken, and undulating surfaces, imposes heavy shocks upon the structure. With marine aircraft the measure of the severity of such shocks depends entirely upon the conditions of weather and water, and the degree of skill with which the manoeuvring on, off, and on to the sea takes place. Similar conditions affect landplanes but with this great difference: incorporated in these latter, without exception, are devices which damp out the sharpnesses of impacts, smooth out abruptnesses, and aim to preserve for the remainder of the structure an evenness of keel and beam, while they themselves are resilient and accommodating, adjusting and readjusting themselves to the contact, speed, angles, and varying conditions (within reason) of the surface over which they are travelling. Such devices (which have been tried, too, on seaplane floats, but without sufficient success) have mostly taken the form of ties working in tension, or telescopic legs working in compression, and incorporating systems (singly or in combination) of elastic, rubber rings, bands, or balls, springs, oil through orifices, valves, or dashpots, and compressed air, which are directly interposed between the aircraft structure and the points of contact with the earth, whether skids, skis, or wheels. (It should be observed, incidentally, that pneumatic tyres on the last-named form, of course, in themselves excellent additional cushions). The devices form part of the main strut (or tie, as the case may be) system of the landing gear.

Of the methods of shock absorption mentioned, the general trend is to adopt at all points pneumatic tyred wheels in conjunction with the said telescopic legs, such legs being held extended by a system using oil and compressed air. The following is a description of such a device (Vickers Ltd.):

There are few moving parts, and these are automatically lubricated. The main gland is oil-sealed and no air can escape at this point; the filling valve is also oil covered. Both this valve and the oil-level valve are of the needle type and should retain the air indefinitely. The gland on the stem of the filling valve only comes into action during filling or testing operations. In order to obviate the risk which might accompany the removal of the main gland cap or screwed plug whilst there is still pressure in the air cylinder, the oil-level valve is interlocked with this part. It is therefore necessary to remove completely the oil-level valve before proceeding to dismantle the unit. The working surfaces of the air cylinder and piston are ground. The principle on which the system works is that any inward movement of the piston will compress the air. The increase of load due to increasing air pressure follows a definite law, and is practically independent of speed.

A large degree of lateral stability is given to the machine when taxying.

The piston is always under air load and is always striving to return to its extended position. When the piston is forced inwards the oil is forcibly ejected by the entry of the brake ram and caused to pass into the interior of the air cylinder through the annular orifice. This orifice is of relatively small area, and the velocity of the oil through the same is very great and consequently gives rise to a high pressure in the chamber, with a corresponding retarding effect on the piston. The oil brake converts the excess energy of the landing into heat; this heat appears in the oil and is immediately dissipated by radiation from the exterior of the unit. The amount of energy which the oil brake is called upon to deal with, and the retarding force which it exerts, depend upon the speed at which the piston moves. If the piston is pushed in gently the retarding force of the brake will be negligible. The form of the brake ram provides the necessary retarding force as the speed of the machine falls away in coming to rest. With this combination it will be seen that great amounts of energy can be absorbed and dissipated without overstressing the machine structure.

The outward movement of the piston is controlled by an oil dashpot, which acts as follows. As the piston moves inward an annular space is formed between the piston head and the lower part of the cylinder. This space is filled with oil which passes freely through holes in the piston head and around the plate valve, which is suspended from the piston head. When the piston commences to move outward the plate valve closes and traps the oil. The rate of return of the piston is then controlled by allowing the oil to pass back to the air chamber through a small hole in the plate valve. The speed at which the piston returns is sufficiently great to enable the wheels to meet recurring shocks in taxying, but not sufficiently great to cause bouncing. The main gland is self-adjusting and is packed with oil-tight rings.

The proper action of the strut or leg depends upon the oil quantity and air pressure being maintained within reasonable limits. When the strut is initially assembled a stated quantity of oil is put into the cylinder. As the main gland is absolutely oil-tight, and as we may assume that the unit will be serviced with dry air, there is no further need to test the oil level until the strut is dismantled for reconditioning at the end of one year, or earlier if a fault develops.

The struts are best stored filled with the measured quantity of oil but with no air pressure. If it becomes necessary to store them with air and oil ready for immediate use, then they must be stacked in a vertical position, cylinder on top. The best air pressure for a given application is found by trial, but as a general rule the air pressure is such that the piston floats at 75 per cent extension when the machine is at rest and carrying full normal load. Any variations between light load and overload are accommodated automatically by the movement of the piston outward or inward until the air pressure balances the load. The state of air pressure in the units on a machine can be readily determined by inspection of the red indicator line usually painted on the oleo fairing. This line is about 1 in. wide and so long as part is visible when the machine, at rest, is carrying full load, the air pressure is right. The freedom of the pistons can be checked by noting the amount of piston travel in normal use; this movement should be at least 50 per cent of maximum possible travel. The air pressure stated on the instruction label is that which is obtained when the piston is fully extended and carrying no load.

Some ground engineers insist upon testing the oil level and the pressure in the unit at stated periods when in service. This is not normally essential in view of the above, but verification when necessary may readily be

The methods of repair vary in accordance with the type of construction used, and it is obvious that a repair which is suitable for one type of aeroplane will in most cases not be suitable for another type. It is highly important, therefore, that only those repairs should be used which have been approved for the particular type of aircraft, and which are enumerated in the repair notes.

Rigging Allowances

Rigging notes and instructions generally give the angles and dimensions in exact figures, but in practice it is seldom possible to work to the exact dimensions given. A tolerance is therefore permissible on all dimensions.

The allowances to be made vary with different aircraft, obviously depending mainly on the type and size of the aeroplane and the magnitude of the dimension.

The utmost care must be taken to avoid damage to the structure owing to an attempt to work to too strict a tolerance; on the other hand, no effort should be spared to obtain the closest approximation to the rigging dimensions that the normal adjustments will allow.

Inspection

After re-assembly, necessitated by repairs, the aeroplane should be completely inspected before it is passed as fit for flying. The inspection should be made methodically and in accordance with a system. The system usually adopted is to divide the aeroplane into a number of logical and convenient groups, and deal with each group in a definite order. The grouping normally employed is: undercarriage, fuselage, tail unit, cockpits, mainplanes, airscrew, and general. During the inspection of each group, the inspector should, as far as the group lends itself to such procedure, always go round it in an anti-clockwise direction, examining each individual part in detail as it is encountered.

Detachable Fairings

When the flush fitting type of cowling clip is used, special precautions must be taken to ensure that the clips are actually securing the fairing to the structure, as the fairing is in a dangerous condition if one of the clips does not catch as it should. It is usual to arrange for the screw-driver slots or other operating mechanism to be all in one direction so that the position of the catch can be ascertained at a glance. If this has not been arranged, suitable marks should be made on the clip, the marks being all in one direction when they are attached.

Protection Against Corrosion

One of the greatest enemies of metal aircraft parts is corrosion. An infallible and everlasting remedy for corrosion which is of practical utility has yet to be found for the majority of ordinary metals. The greatest advance within recent years was the introduction of stainless steel. The use of this material, of which there are several varieties, appears to be a solution of many problems connected with corrosion. Materials used on aircraft which demand the greatest care from the aspect of corrosion are ordinary steels and light alloys. Steels by themselves do not corrode at a greater rate than many other metals, but on account of their greater tensile strength they are generally used in much thinner gauges than other materials, and are therefore more susceptible to deterioration owing to this cause. Light alloys which have a basis of aluminium or magnesium are inherently unstable, and given an opportunity will corrode very

which the pump is disconnected. Finally make all valves safe and replace the dust-cap.

It is essential that the piston be fully extended when the unit is being checked for oil level and air pressure. No attempt should be made to increase the air pressure beyond that indicated on the label. The sliding external portion of the piston should be kept free of any sand or grit.

A number of hypothetical cases with faults, reasons, and remedies are here given—

(*a*) Piston does not move or only moves a small amount when taxying.	Air pressure too high, or gland has become gummy through long period of inaction. Remedy—reduce air pressure.
(*b*) Piston does not extend to normal and machine wallows on a turn.	Air pressure too low.
(*c*) Piston extends normally and air pressure is correct, but machine still rolls over badly on a turn.	Oil level too low and air pressure does not increase fast enough with inward motion of piston. Remedy—check oil level.
(*d*) Piston at normal extension and air pressure correct, but machine very harsh on taxying.	Oil level too high, causing undue increase of air pressure with movement of piston. Remedy—check oil level.
(*e*) There is evidence of loss of oil at main gland.	If leakage is very slow keep unit in commission by maintaining air pressure. Replace complete unit as convenient. The gland of the defective unit must be dismantled and faulty packing rings replaced.
(*f*) If the air pressure in the unit is not maintained.	Ascertain that all valves are tight, and if the leak still persists detach unit and submerge in water to locate fault.

Tail Skid

Tail skid types vary. A tail skid usually consists of a simple lever of the first order, the fulcrum of which hinges on a post or tripod arrangement fixed in the fuselage and having a shock absorbing medium for balancing the load at one end and a hard-wearing shoe at the other. The skid may be fixed, or may be freely tracking, or may be controlled partially or wholly in unison with the rudder.

The skid should be examined for buckling or fracture, the fulcrum points for slackness, struts or stays for bending, attachment lug holes for elongation, pins for shear, collars and bearings for wear, the shock-absorbing medium for general soundness, and the whole for general locking and security.

The tendency upon modern aircraft is to incorporate a small oleo-pneumatic strut (see "Shock Absorbing Devices") in conjunction with a tyred wheel (see "Wheels" and "Tyres").

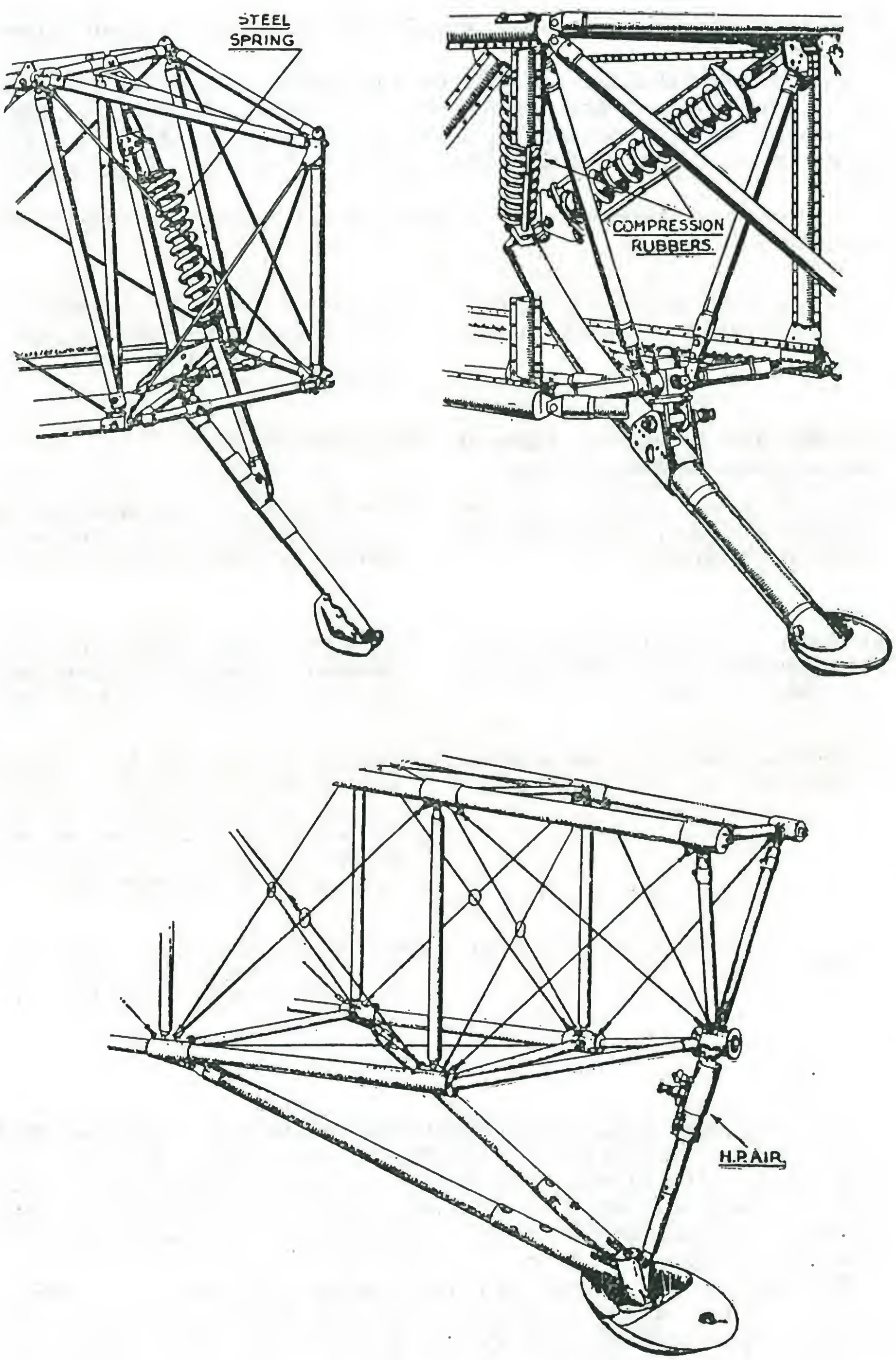

FIG. 40. TYPICAL TAIL SKIDS
(From A.P. 1107, by courtesy of the Controller, H.M.S.O.)

Tyres

The purpose of the aeroplane tyre is to interpose a pneumatic cushion between the aeroplane and the ground surface and to prevent undue shocks being transmitted to the aircraft, i.e. to minimize irregularities when taxying to take off, or in the final run after landing, and to act as a shock absorbing medium when the aircraft first touches the ground on landing. The successful use of pneumatic tyres depends upon the maintenance, whether the tyres be in service or standing by, of the correct inflation pressure for the load as recommended by the manufacturers.

Maintenance

(*a*) Excessive wear may be due to the wheels not being in line.

(*b*) It is harmful to allow tyres to stand or to become bespattered with oil or grease.

(*c*) Tyres become badly cut about from flints and other sharp objects. The covers should be periodically examined for deep contusions.

(*d*) In some cases the inner plies of the covers break down and may give rise to swellings. Should a hand lightly passed over the cover be sensible of such swellings the cover should be removed, and if fractures are in fact existent a new cover should be fitted.

(*e*) Tyres under ordinary and normal circumstances should be taken down for general examination and for inspection at any signs of perishing.

(*f*) Tyres preserve their structure and resiliency best in a cold and damp atmosphere; so far as conditions permit, therefore, and without prejudice to other parts of the aircraft, continued heat and dryness should be avoided.

(*g*) Should the aircraft be stored, jack up so that no weight remains on the tyres. If this is inconvenient, move the aircraft periodically to ensure a fresh area tyre is in contact with the ground.

The complete tyre should always be maintained in a good and sound condition. It should be borne in mind that a tyre-burst or failure whilst an aircraft was landing or taking-off at speed would be a dangerous and hazardous happening.

Wheels

Care should be taken during removal or fitting operations to avoid any damage to the protective surface coating. The bearings should be re-packed with grease from time to time, and in the case of wheels fitted with brakes more care is necessary with lubrication. Over-lubrication may result in grease finding its way on to the brake drum and impairing the efficiency of the brake.

Flotation Bags

These may be fitted in land aircraft to provide a period of buoyancy in the case of a forced descent upon water. The bags are interconnected by piping, and remain open to atmospheric pressure, a stop-cock being closed by hand immediately prior to the "landing." The material from which the bags are made is a rubberized fabric, which should be examined for deterioration when in use. Points of likely damage or chafing against the structure should be suitably taken care of. The system should be pressure tested to $\frac{1}{4}$ lb. per sq. in. (or 7 in. head of water) by means of a U-tube. The fall in pressure must not exceed $3\frac{1}{2}$ in. of water during test.

A suitable period should be allowed to elapse between the initial imposition of pressure and the test, to permit the temperature of the air in

(Extracts from A.I.D Leaflet 11A, by courtesy of the Controller, H.M.S.O.)

the system to equalize with that of the shop or hangar. Any drop in pressure observed should be corrected before the actual test is commenced. Care should be taken that the air bags are not exposed to radiant heat (direct sun's rays) during test. Bags may be individually tested by the application of soapy water (which must afterwards be properly washed off) around seams.

11. GENERAL MAINTENANCE AND MINOR REPAIRS

Cleanliness

The fabric of the aircraft must be kept clean and free from oil, in order to avoid deterioration. To remove dirt and oil from the fabric, rub it well with a piece of waste or rag soaked in warm soapy water. Having removed all dirt and oil, wipe the fabric with a piece of dry cloth.

Mud thrown on to the fabric by the wheels of the undercarriage should not be allowed to dry, but should be removed as soon as possible. If, however, it has become dry, it should be taken off with warm water and not scraped off, as the fabric is liable to be damaged by scraping.

Control Wires

After every flight pass the hand over the control wires and carefully examine them near pulleys and fairleads. Even if only one strand is broken the wire must be changed. The aileron balance wire on the top plane must not be forgotten. Once a day try the tension of the control wires by moving the control levers about smartly.

Wires

See that all wires are kept well greased or oiled, and that they are adjusted to the correct tension. When examining the wires, make sure that the aircraft is on level ground, as otherwise it may get twisted, throwing some wires into undue tension and slackening others. The best way, if you have time, is to pack the machine up into its "rigging position." Should a slack wire be discovered it does not follow that this should be tensioned. The aircraft should be placed in rigging position and the cause traced. It may be that the opposite wire is stretched, the fitting pulled, or a component bowed, etc.

Carefully examine all wires and their connections near the airscrew.

Distortion

Carefully examine all surfaces, including the controlling surfaces, to see whether any distortion has occurred. Should distortion be discovered the defect must be very carefully traced and rectified. It may be that a wire has been unduly stressed, causing a rib to buckle. Slackening back the wire would not effect the repair as the rib would have become fractured, or the glue or securing loosened.

Undercarriage

Constantly examine the alignment and fittings of the undercarriage, and the condition of tyres, shock absorbers, and the tail skid.

Special care should be exercised when examining the "Oleo" type undercarriage.

Cleaning of Metal Fittings

When metal fittings require cleaning, all forms of scraping, such as rubbing with emery cloth or a wire brush, should be avoided. A paraffin bath and a soft brush or rag soaked in paraffin should be all that is required.

When removing paint or varnish, no abrasive methods should be employed, but the covering material should be softened with the varnish remover and rubbed with a rag soaked in this solvent. Stove-enamelled fittings are not usually treated with zinc or cadmium, and therefore the normal methods of removing stove enamel may be employed. After removal of the defective paint or varnish, all fittings should be re-coated with the appropriate protective covering with the exception of the side and bottom fuselage cowlings and the metal parts of undercarriages and radiators. These parts, if desired, need not be re-painted, but may be kept clean and bright by using metal polish or an oil-soaked rag.

Inspection Doors in Planes

Metal inspection doors in main planes should be very closely watched, especially if situated in the slipstream region, as fastenings which would normally be regarded as quite secure may possibly become detached through vibration and the effects of the slipstream. Should this occur the inspection door may fly back with considerable force, involving a possible injury to the pilot or the fouling of control mechanisms.

Rip Off Patches on Planes

Inspection doors are usually provided only at those positions where frequent inspection or lubrication of the internal fittings is required. Where only occasional inspection or adjustment is required for internal fittings, such as bracing wires, a special form of patch is used which is capable of being torn off and renewed as necessity demands. There are several types and shapes, but in all cases a light frame is secured to the fabric covering of the wing and the fabric enclosed by the frame cut away, thus providing a hole with a non-frayable edge. A covering patch of frayed fabric large enough to envelope the frame is then doped on to the plane over the hole. When it is necessary to place a rip off patch on a plane, the frames should preferably be of the circular type with an internal diameter of $4\frac{1}{2}$ in. to 5 in., but other shapes can be adopted to suit special conditions.

Care of Shock Absorbers

The shock absorber legs on the undercarriage of any aeroplane should be of equal length under any given load, and where this is not the case, an examination should be made to ascertain the cause of the unequal extension. Gauge marks are normally provided to indicate the approximate safe minimum length.

Repairs and Maintenance

After an aeroplane has been assembled and flown, there are manifold duties connected with the maintenance of the aeroplane in a sound and airworthy condition. This entails a regular and systematic examination of all parts, with the consequence that adjustments and minor repairs are found necessary from time to time, quite apart from the repairs necessitated by a more or less serious mishap to the aeroplane such as might be occasioned by a forced landing. If an aeroplane is seriously damaged, but not sufficiently for it to be struck off charge, it is usual to strip the aeroplane completely, dismantle the damaged portion, substitute complete components for those badly damaged, and repair the parts which are only slightly injured. The repair and maintenance notes for the type usually specify the limit of repairable damage, and the details provided generally cover all normal eventualities. The repair and maintenance notes are either issued separately or incorporated in the aeroplane handbook.

The methods of repair vary in accordance with the type of construction used, and it is obvious that a repair which is suitable for one type of aeroplane will in most cases not be suitable for another type. It is highly important, therefore, that only those repairs should be used which have been approved for the particular type of aircraft, and which are enumerated in the repair notes.

Rigging Allowances

Rigging notes and instructions generally give the angles and dimensions in exact figures, but in practice it is seldom possible to work to the exact dimensions given. A tolerance is therefore permissible on all dimensions.

The allowances to be made vary with different aircraft, obviously depending mainly on the type and size of the aeroplane and the magnitude of the dimension.

The utmost care must be taken to avoid damage to the structure owing to an attempt to work to too strict a tolerance; on the other hand, no effort should be spared to obtain the closest approximation to the rigging dimensions that the normal adjustments will allow.

Inspection

After re-assembly, necessitated by repairs, the aeroplane should be completely inspected before it is passed as fit for flying. The inspection should be made methodically and in accordance with a system. The system usually adopted is to divide the aeroplane into a number of logical and convenient groups, and deal with each group in a definite order. The grouping normally employed is: undercarriage, fuselage, tail unit, cockpits, mainplanes, airscrew, and general. During the inspection of each group, the inspector should, as far as the group lends itself to such procedure, always go round it in an anti-clockwise direction, examining each individual part in detail as it is encountered.

Detachable Fairings

When the flush fitting type of cowling clip is used, special precautions must be taken to ensure that the clips are actually securing the fairing to the structure, as the fairing is in a dangerous condition if one of the clips does not catch as it should. It is usual to arrange for the screw-driver slots or other operating mechanism to be all in one direction so that the position of the catch can be ascertained at a glance. If this has not been arranged, suitable marks should be made on the clip, the marks being all in one direction when they are attached.

Protection Against Corrosion

One of the greatest enemies of metal aircraft parts is corrosion. An infallible and everlasting remedy for corrosion which is of practical utility has yet to be found for the majority of ordinary metals. The greatest advance within recent years was the introduction of stainless steel. The use of this material, of which there are several varieties, appears to be a solution of many problems connected with corrosion. Materials used on aircraft which demand the greatest care from the aspect of corrosion are ordinary steels and light alloys. Steels by themselves do not corrode at a greater rate than many other metals, but on account of their greater tensile strength they are generally used in much thinner gauges than other materials, and are therefore more susceptible to deterioration owing to this cause. Light alloys which have a basis of aluminium or magnesium are inherently unstable, and given an opportunity will corrode very

quickly. The corrosion which occurs in these materials is not always attributable to exterior causes, but it may be due to the interaction which occurs, due to impurities in the metal. For both steels and light alloys the basic principle of protection against corrosion is to exclude the air from contact with the metals. If, therefore, corrosion is to be avoided, it is imperative that the protective covering should remain intact, or if, owing to mishandling or service usage, the protective covering has become damaged, it should be renewed immediately. The usual protective media employed include paints, varnishes, enamels, sherardizing, hot galvanizing, coslettizing, cadmium plating, anodizing, and metal spraying, all of which have been devised with the object of defeating corrosion.

CHAPTER III

SEAPLANES AND FLYING BOATS

12. ORDER OF ERECTION (FLYING BOATS)

PRIOR to the erection of the component parts of the aircraft, the hull, supported in its cradle, is adjusted to rigging position. The order of erection adopted by manufacturers is as follows—

1. Hull adjusted to rigging position.
2. Tail unit erected on ground and lifted into position.
3. Bottom centre plane attached and engine mountings (with oil tanks) assembled.
4. Petrol tanks installed in top centre plane, and top centre plane, with centre section struts, fitted.
5. Engines installed.
6. Top outer planes erected with ailerons in position.
7. Outer interplane struts attached and bottom outer planes, with ailerons, erected.
8. Interplane struts, aileron struts and bracing wires connected up.
9. Wing tip floats fitted.
10. Alternatively the complete superstructure can be assembled on suitable trestles and lifted as a unit on to the hull.

13. RIGGING

Levelling Boards

A complete set of straight-edges, incidence and dihedral boards for the rigging are usually supplied by the manufacturers. (The incidence and

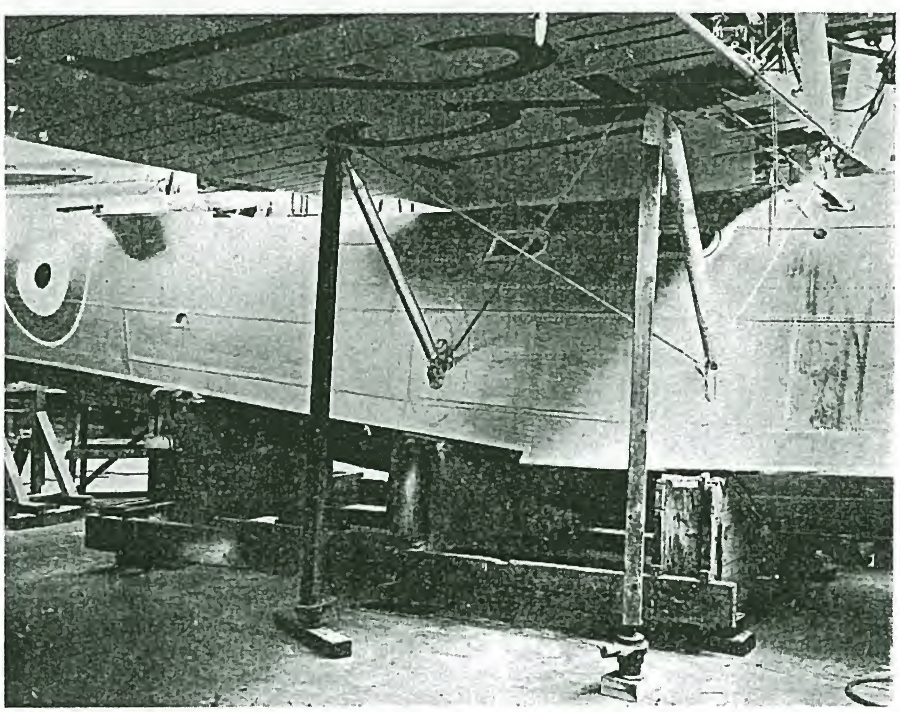

FIG. 41. HULL IN CRADLE AND PROPS UNDER PLANE CHOCKING BLOCKS

dihedral boards are illustrated and the method of use shown in Figs. 6 and 7, Chapter I). If the boards are not available the aircraft can, of course, be rigged in the usual manner by measuring the angles with a straight-edge and inclinometer.

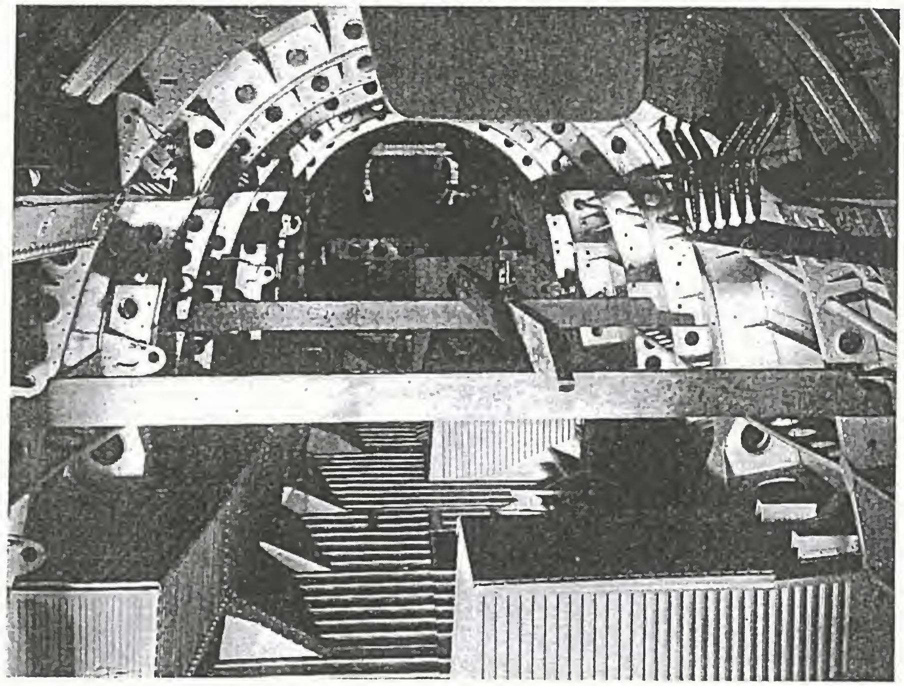

FIG. 42. PERMANENT LEVELLING BLOCKS (SHOWING STRAIGHT-EDGES IN HULL)

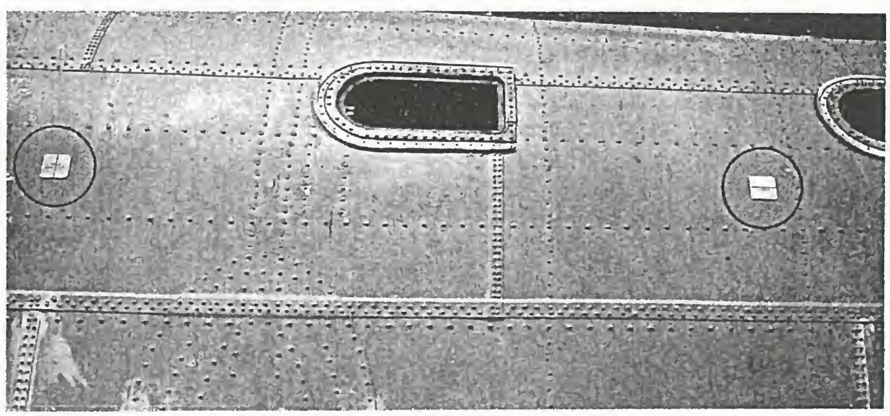

FIG. 43. DATUM-MARK PLATES ON OUTSIDE OF HULL

Rigging Position

The construction of the hull does not allow any adjustment or truing up. The hull is placed in position on its supporting cradle and the latter adjusted by means of suitable wood packing blocks and wedges (Fig. 41) until the straight-edges are horizontal laterally when placed inside of the hull on the permanent levelling blocks, positioned as indicated in Fig. 42,

and longitudinally either by level and straight-edge along the datum lines (see Fig. 43) or internally by bridging straight-edges on the two lateral stations by a straight-edge fore and aft.

Assembling the Tail Unit

The tail unit should be placed on felt-covered boards arranged to give adequate support to the under-surface; then the fins, rudders, inter-rudder struts, elevators, and control connecting rods are assembled. The complete unit can then be lifted into position, and attachment made to the hinge fittings on the hull and the main spindle of the adjusting gear. The struts and auxiliary stays from the hull to the tail plane front spars, and the struts from the lower end of the adjusting gear spindle to the rear spar are then fitted, and the complete unit trued up. The lower (hull) ends of the tail plane struts are usually provided with adjustable sockets which are secured to the lug plate fittings on the hull and tail adjusting gear. Short straight-edges, laid along the spars on either side of the central fin, should be horizontal when the hull is in rigging position. If necessary, adjust the struts to secure this condition.

It is sometimes found that alteration of the length of the tail plane struts produces slight local distortion of the stern of the hull, with consequent binding of the rudder and elevator transverse torque shafts. Particular note must be taken, after erection of the tail unit, that these shafts are quite free to rotate.

Assembling and Rigging the Centre Section

The centre section may be assembled in two ways; either by erecting the bottom and top planes separately, or by assembling the whole unit and lifting it on to the hull. Where facilities exist, the latter is the best and the most convenient method.

When the planes are to be erected separately, the bottom centre plane is lifted on to the hull and the front and rear spar attachments completed. The front and rear support struts from the hull (the upper ends of which are adjustable) together with the incidence bracing are then attached, the plane being supported at the ends meanwhile. The bottom plane should then be tested for horizontal level, using the blocks provided for that purpose. The incidence of the plane should now be checked. If necessary slight adjustment for incidence can be made by varying the length of the supporting struts. At this stage it is advisable to test the bottom plane for squareness to the centre line of the hull. This is checked by measuring the distance of a point on each end of the front spar from a point at the nose and on the centre line of the hull; these distances should be equal. If any adjustment is necessary it can be effected by means of the under centre section bracing. In some types of aircraft which have built-in bottom centre sections as an integral part of the hull, no provision is made for the adjustment of the lower centre section after the hull is completely plated.

The top centre plane may now be erected. The plane is lifted into position with all the interplane struts fitted. When completely erected, the stagger, if any, of the two planes must be checked by dropping plumb lines from the leading edge of the top centre plane (see Fig. 8). Care must be taken that all struts are fitted in the correct position, as some may have dead length struts, and some adjustable screwed sockets in the lower ends.

This screwed type of socket is a standard one for adjustable struts which are structural members of the aircraft. In altering the length of any of these, care must be taken to ensure that the male portion of the

socket is not screwed out so far that it cannot be felt when a wire is inserted in the inspection hole drilled in the strut end, as otherwise the number of threads of the socket engaged in the strut will be insufficient for strength.

Where it is possible to lift the complete centre section as a unit on to the hull, the following procedure should be adopted. Raise the bottom centre plane on trestles, suitably padded and preferably set to the correct incidence, and then assemble on it the top plane (with petrol tanks) interplane struts, incidence bracing wires and engine mounting. Completely true up the centre section. Lift as a unit on to the hull and complete the attachments. Tests can then be made for horizontal level and incidence of the bottom plane, stagger if required, and squareness of the centre section with the hull.

Attaching and Truing Up Outer Main Planes

Where only one pair of interplane struts is used for each outer section, it is not possible to "box up" the outer planes on the ground and hoist into position. The top planes, with ailerons held fast in neutral position by top and bottom battens, secured by bolts and wing nuts through the space between wing and ailerons, are erected first, and supported by slings, whilst all the interplane struts are attached and both bottom planes erected. The struts are then attached to the bottom planes and the front and rear landing wires inserted. As a precaution an extra support should be arranged under the engine mounting on the side of the first bottom plane erected, to take the weight and thus counteract any tendency to disturb the hull in its cradle. The incidence and flying wires are then fitted and all supports removed. Lastly, the interplane bracing is trued up until the correct settings are obtained.

Assembling the Wing Tip Floats

The float struts should be fitted to the floats before attaching to the planes. Attach the float struts to their respective fittings on the front and rear spars and the bottom outer planes, then fit the incidence and bracing wires. When correctly erected the float struts should be at right angles to the undersurface of the plane. All incidence and bracing wire pin centres must be trammelled for equal measurement.

Alternative Method of Erecting Complete Superstructure

Where suitable lifting tackle is available the complete superstructure, centre section, outer planes, interplane struts, petrol tanks, engine mountings, engines, and bracing wires can be assembled on the ground and lifted into position on the hull. If the superstructure is assembled on suitable trestles the wing floats can also be attached, but if assembly is carried out on the ground, or on low trestles, the floats must, of course, be attached subsequent to erection of the superstructure on the hull.

Check Rigging as Follows—

1. Incidence throughout.
2. Dihedral of top planes.
3. Dihedral of bottom planes.
4. Stagger and sweepback on centre section, if any.
5. Stagger and sweepback on outer main planes, if any.
6. Different dihedral of the top and bottom outer planes produces a backward sweepback of the bottom plane, compared with the top plane, measured at the outer struts.
7. Engine mounting for alignment.
8. Tail plane incidence with adjustment each way from normal position.

Final Check

The usual final check measurements for symmetry of the complete aircraft should be made.

These should include the following—

1. Sternpost to foot of front outer interplane struts.
2. Nose of hull to foot of front outer interplane struts.
3. Outer tips of tail plane front spar to centre line of hull just aft of the trailing edge of bottom centre plane, also to foot of front outer interplane struts.

Rigging of Float Undercarriage

The aircraft should be set up with fore and aft and transverse datum lines horizontal.

The longitudinal centre lines of each float must lie truly parallel with

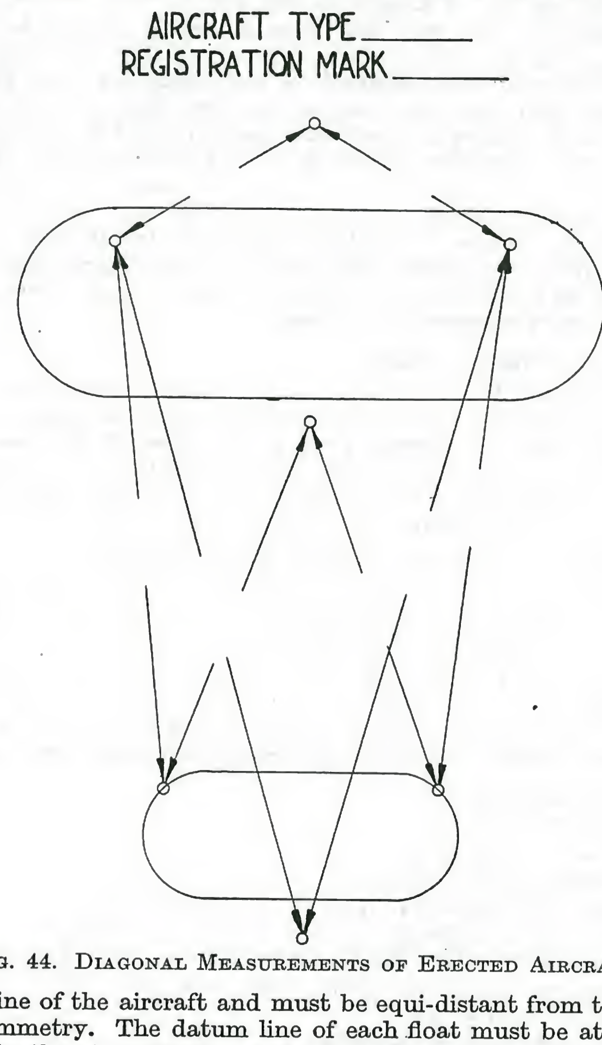

FIG. 44. DIAGONAL MEASUREMENTS OF ERECTED AIRCRAFT

the centre line of the aircraft and must be equi-distant from the aircraft's plane of symmetry. The datum line of each float must be at the correct inclination to the aircraft's fore and aft datum and the plumbed distance between an important item on a spar (or a formed-extension of the points

of attachment of the undercarriage to the fuselage) to a common point on each float must be equal.

The fore and aft horizontal distances between common points on each float and key position on the aircraft must be equal. The distance between a common point towards the bow of each float and a common point towards the stern of the other should be equal.

The individual floats should be checked to see that the dorsal or the centre of the top surface is plumb over the keel or centre of the planing bottom.

The particulars should be entered in a form similar to Fig. 44.

Water Rudders

Water rudders are sometimes provided for seaplanes, being usually operated by the rudder bar and situated on float seaplanes at the aft end

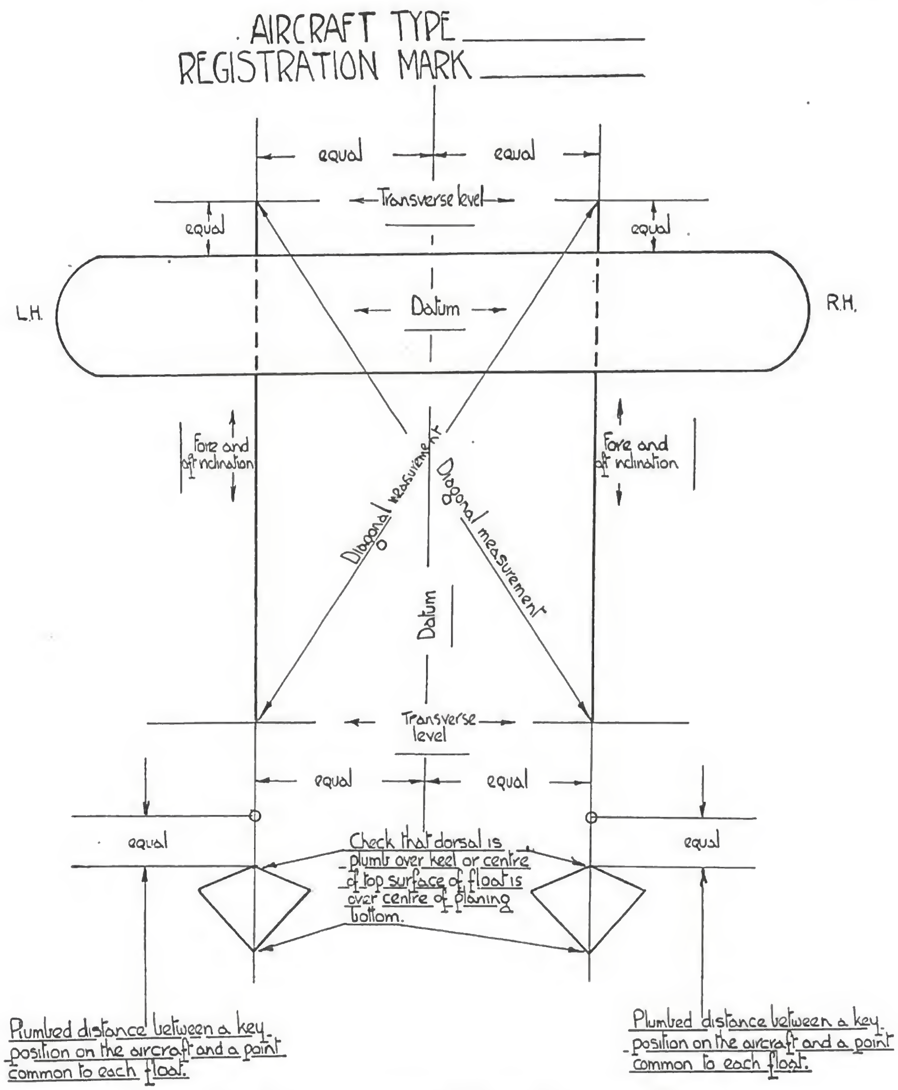

FIG. 45. SEAPLANE MAIN FLOAT RIGGING DIAGRAM

of the floats, in a similar position to that occupied by a normal ship's rudder. Water rudders are seldom used for boat seaplanes, mainly because all the control normally required is obtained from the engines, of which there are usually two or more. Water rudders are a normal part of amphibian aircraft.

14. GENERAL MAINTENANCE AND MINOR REPAIRS OF HULLS AND/OR FLOATS

Repairs of Hull and Floats

The treatment of a particular repair is very largely at the discretion of the repairer, and these notes are intended only as a guide. Every effort should be made to restore the damaged parts as nearly as possible to their original strength and condition, and the methods employed in building must follow closely the directions in manufacturers' handbooks.

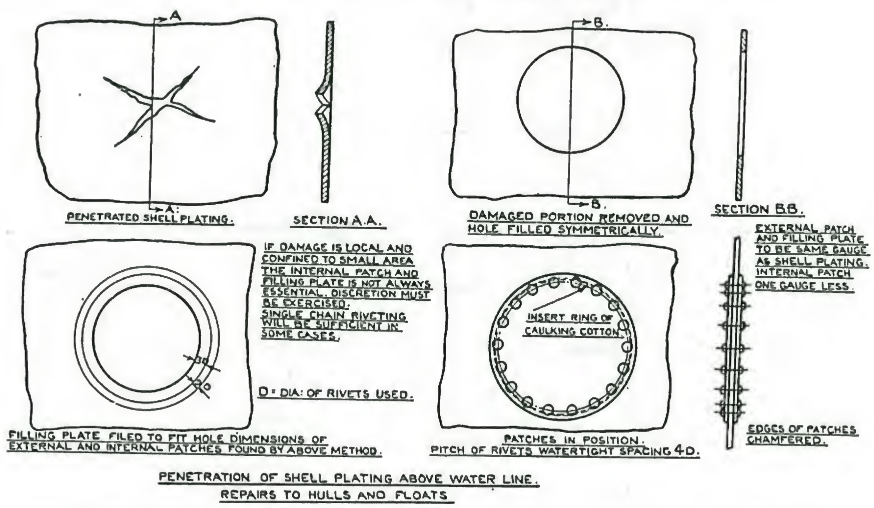

FIG. 46. REPAIRS TO HULLS AND FLOATS ABOVE WATERLINE

When repairs are carried out the plating, rivets, etc., must be to the same specification as the material being replaced; this is very important where the hull and/or floats are constructed of stainless steel, as electrolytic action takes place between various stainless steels. The size and spacing of the rivets should be the same as that found in similar parts of the structure. Patches must be riveted round the edges with the size and pitch of rivets used in the plate being patched. Rivet holes must be drilled, and the patch carefully closed to the plate with bolts before riveting is commenced. Rivets are best removed by cutting off the heads with a small cold chisel and light hammer and punching out the shank. Where the plating is perforated the jagged edges should be "faired up" or cut away, preferably to a square, oblong or circular shape, and a patch of similar (but, of course, larger) shape fitted and riveted outside (see Fig. 46).

If the repair is on a part of the structure with a pronounced curvature, the patch must be curved or beaten to shape so that it goes into position without being forced. The rivets must not be worked in consecutive order, but at intervals, otherwise the material will stretch and the rivet holes

(Figs. 46, 47, and 48 from *A.P.* 1147, by kind permission of the Controller, H.M.S.O.)

will not coincide. Where a very quick repair is necessary to under-water plating of a boat there is no need to cut out the damaged part. The piece used for patching must be large enough to lap over the part of the plate remaining fair. In making a quick repair, fix the patch by using small

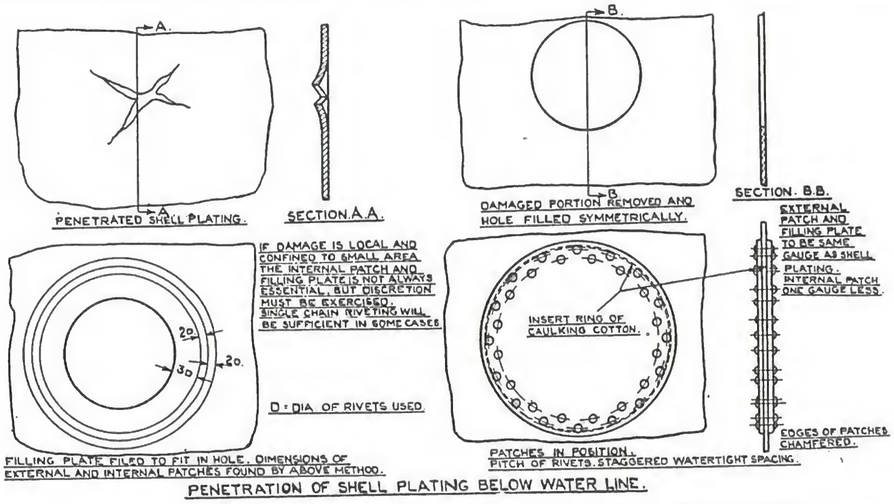

FIG. 47. REPAIRS TO HULLS AND FLOATS BELOW WATERLINE

bolts instead of rivets. Proper patching in accordance with Fig. 47 must take the place of this makeshift repair as soon as the aircraft base is reached.

Joggled Patch

Damage at a seam or butt insufficient to warrant the removal of two whole plates would normally be repaired by a joggled patch where facilities

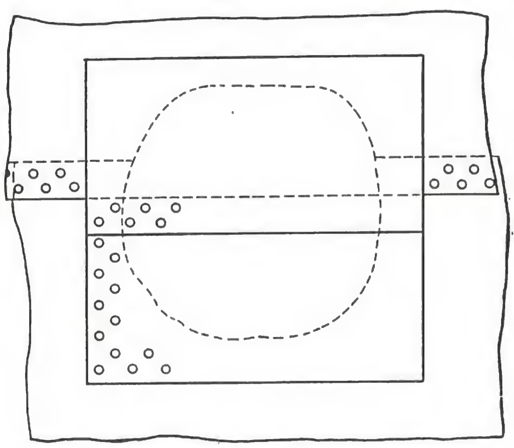

FIG. 48. JOGGLED PATCH

for joggling the plate do not exist; the difficulty in making a watertight joint where the patch crosses the leading edge of the seam may be overcome as shown in Fig. 48.

In this case two pieces are used, one butting against the edge of the outside plate and the other lapped over the first. If duralumin rivets are

used during repair work they must be heat-treated, before use, at the normalizing temperature (480–490° C.) and riveted up within 1 hour of treatment. Lower temperatures during heat treatment will render the rivets more liable to corrosion. Should a repair be carried out and no

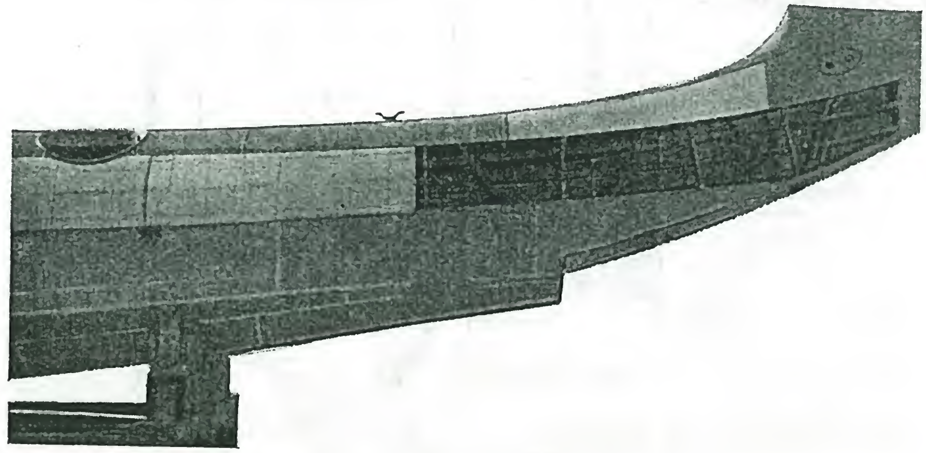

FIG. 49. HULL PLATING BEFORE COMPLETION OF REPAIRS

approved protective covering be available, the parts should be treated with grease, until the proper coating can be applied.

Figs. 49 and 50 show a hull during and after plating repairs.

Note—Preservation of the structure's poise should always receive adequate attention. It will be seen that if old plates are taken off at

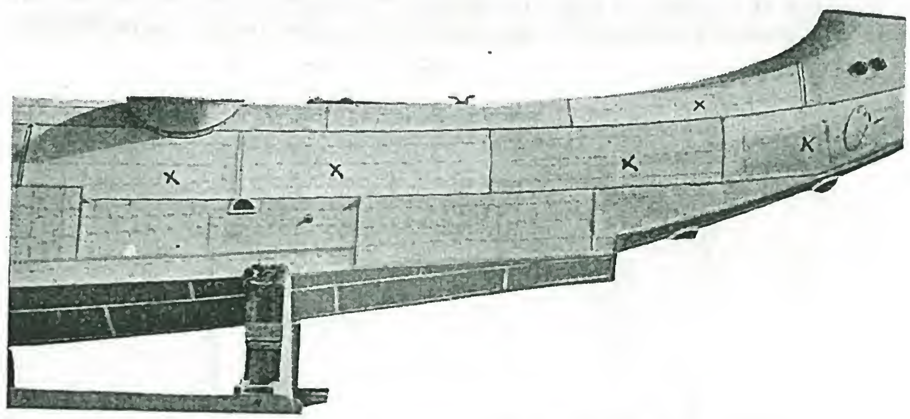

FIG. 50. SHOWING PLATING OF HULL AFTER REPAIRS

random dangerous distortion or even collapse of the structure may occur. Where more than one plate is taken off at a time, therefore, it should have been previously verified that the structure is well able to bear such a loss.

Test for Watertightness

HULL

After all repairs check all watertight seams; laps and collars are usually caulked with putty and white paint and cotton, but other approved

methods may be laid down in the manufacturer's handbook. A water test may be carried out as follows—

(*a*) Fill the hull with fresh water to the level of the waterline, and leave for a period of 1–1½ hours; then examine the exterior for leaks, and if any leaks are noted carefully mark same. The hull should then be emptied and the whole of the remaining plating and joints should be tested by spraying water on to all seams, etc., outside the hull, by the use of a hose pipe fitted with a small nozzle giving a fine jet of water at high pressure. Examine at the same time all joints, etc., inside the hull.

(*b*) If the hull is not filled with water, the whole of the plating and joints should be sprayed externally as already described in the latter part of paragraph (*a*).

Floats

During repairs all watertight seams, laps, collars, and bulkheads are usually caulked with putty and white paint, and, where joggled with cotton, each compartment is finally tested separately by filling with fresh water to a depth of 10–12 in. This is allowed to stand for 5–15 minutes, the keel, bulkheads, and keelson being examined. The float is then turned on to its side and the chines examined. After securing the watertight covers, again turn the float so that all remaining joints can be tested.

General

All laps and seams are tested by spraying the water into the other side of the lap or seam. Where leaks occur the joints should be caulked and re-tested; in the case of individual rivets leaking these should be replaced.

Maintenance of Hulls and Floats

On no account must sea water be allowed to remain inside the hull. The interior should be carefully wiped out, particular attention being given to small crevices where water is liable to accumulate. The wing tip float inspection covers should be removed and any leakage water drained off by taking out the drain plugs. Deposits of salt must be cleaned off and wetted surfaces swabbed with fresh water and dried. Abrasions of the external and internal surfaces of hulls and floats must be first coated with an approved undercoat of paint, but this is not to be used over the whole surface on top of the original finishing coat. The deterioration of the top surface enamel will need close attention, and may necessitate the periodical application of a coat of finishing enamel. After this has been done two or three times, the whole of the paint work should be stripped and re-coated. The unlimited application of successive coats of finishing enamel would result in the cracking and flaking off of the thick coating of paint. Also, a large amount of weight would be added by each coat. The old paint should be removed by a suitable solvent such as "Nitro Mors," "Strip off," or any other approved paint remover. Light alloy hulls which are kept afloat for a long period will require special attention, i.e. when hauled up they should be scrubbed down and the bottom immediately cleaned to free weeds and barnacles, before these are allowed to dry on. This is especially necessary in the case of flying boats operating in tropical waters.

During launching and bringing the aircraft ashore it is necessary to take special precautions against damage to the hulls and floats, and for this purpose beach trolleys or a detachable chassis is used. A tail trolley is necessary in addition, when the latter form of chassis is used.

15. MARINE EQUIPMENT: DESCRIPTION AND MAINTENANCE

Mooring and Towing Gear

The gear sometimes takes the form of a main control bridle, painter, and towing bridle.

The main bridle is in two lengths connected by a shackle, the ends being attached to the bow and keel of the hull. The painter connected to the bridle shackle extends some distance to a second shackle. Tow rope and side lines are attached. The side lines run aft from the towing shackle to fittings on the lower centre section, and assist to counteract yawing during towing operations. This gear should always be checked during daily inspection.

Boat Hook

The purpose of the boat hook is for attaching a mooring line from the aircraft to any suitable object within reach. The hook to which the mooring line is attached is provided with a spring loaded tongue to prevent it becoming disengaged from the mooring when its haft is withdrawn.

The boat hook is normally stowed inside the hull at its forward end. An additional stowage is usually provided externally adjacent to the internal stowage.

Ground Anchors

The anchor is of a pattern similar to that used on small launches.

The flukes are detachable from the stock to enable it to be easily stowed.

The anchor, complete with approximately 6 fathoms of cable, is stowed as far forward in the hull bows as possible and is carried in order that the aircraft may be temporarily moored when a mishap has occurred or when no mooring facilities are available.

The anchor in some aircraft is cast and weighed unassisted by manpower, its cable being attached to the aircraft by belaying it on a mooring bollard situated at stem of hull. A small anchor cable drum is sometimes provided, to which the anchor cable is attached and led through a small fairlead in the hull bows. Facilities are provided on this drum for hauling or lowering the anchor.

Sea Anchor or Drogue

The purpose of the sea anchor or drogue is for checking the forward speed and drift of the aircraft and to allow it to ride steadily in a seaway.

In shape it is usually the frustrum of a cone, although alternative shapes are sometimes employed.

It is manufactured in the best quality white canvas and is strengthened at its larger end by a wire hoop, to which the canvas body is attached. At this end a rope loop is provided to attach a cable towing line which is secured to the aircraft, the towing line's length being governed by the type of aircraft to which it is fitted.

The towing wire should be oiled, wrapped with fabric following the "lay" of the cable, stretched and served with balloon cord; this gives additional protection against salt water corrosion.

Stowage is provided for the sea anchor or drogue in an easily accessible position either on the planes or in the hull.

Maintenance Notes

After use the drogues should be hung up and allowed to dry, and at the same time salt water should be removed from the cables and shackles before packing and placing in stowage positions. Stowages should be

checked, and when the drogues are not in use care must be taken that they are easily fastened. After renewal of cables great care must be taken

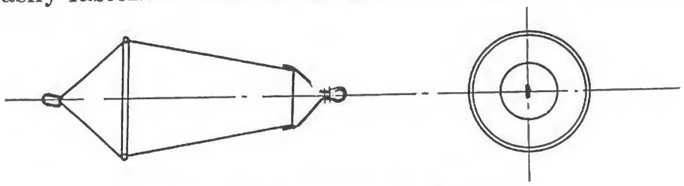

FIG. 51. DETAILS OF ANCHOR

to ensure that the towing wire is attached to the bridle, as cases have occurred where the wire has been fixed to the small end, thus rendering

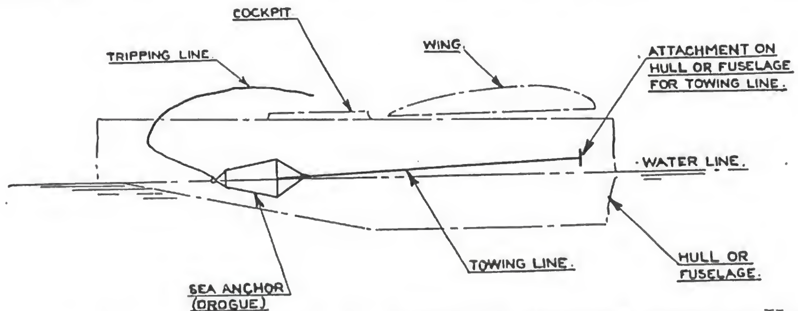

FIG. 52. RELATIVE POSITION OF ANCHOR TO AIRCRAFT WHEN IN USE

the drogues useless, which may result in serious damage or even loss of the aircraft. Therefore the complete system should always be checked.

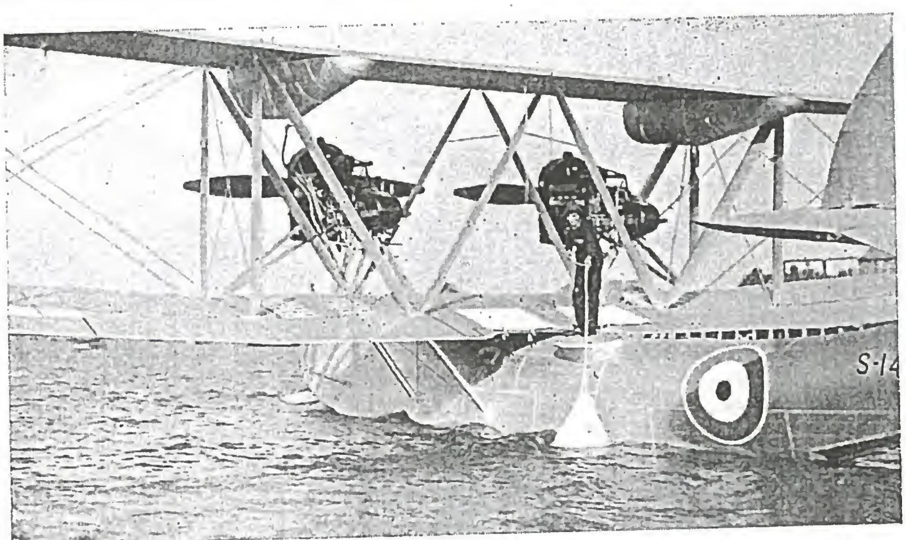

FIG. 53. HAULING DROGUE ON BOARD AFTER AIRCRAFT HAS BEEN MADE FAST AT MOORINGS

Details of the anchor are shown in Fig. 51.

The anchor position relative to the aircraft when in use (see Fig. 52).

Fig. 53 shows drogue being hauled on board after aircraft has been made fast at moorings.

Bilge Pump

This pump as applied to aircraft is a plunger type of approximately 3 in. diameter bore and is provided with suction and discharge hoses for the purpose of clearing the hull bilges of wash.

Stowage is provided in the aircraft for the pump and hose when not in use.

The pump, which is portable, is provided with hinged footholds at its base, which are folded into the pump body when not in use.

The pump can be used at any suitable position in the hull, the suction hose being placed in the hull bilges and the discharge placed over the hull side.

CHAPTER IV

INSTRUMENTS

16. AIR SPEED INDICATORS

(Approved types: Mk. IVA and VB, Pioneer 354 and Korect)

THE air speed indicator is an instrument for use on aircraft to show the speed at which the aircraft is travelling through the air. The instrument at present used consists of a differential pressure gauge mounted on the instrument board and a pressure head fitted outside the aircraft connected to the air speed indicator by tubing.

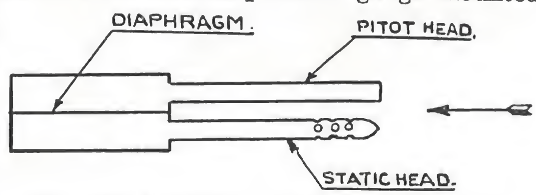

FIG. 54. AIR SPEED INDICATOR DIAGRAM

The principle of the instrument shown in diagrammatic form in Fig. 54 is that it records the difference between the wind pressure due to the passage of the aircraft through the air and the pressure of the surrounding still air.

The Pressure Gauge (A.S.I.)

Of the two most common forms of construction, one consists of an air-tight chamber divided into two compartments by means of a diaphragm. The pitot head is connected to one compartment and the static head to the other. Any change in the pressure in either compartment causes the movement of the diaphragm, which is recorded on the dial by means of a pointer. A disc with a spindle working in a guide is attached to the centre of the diaphragm; as the diaphragm moves the end of the spindle presses against a leaf spring which is deflected in proportion. The leaf spring actuates a bell crank lever, one arm of which projects through a slot in a metal plate pivoted on an axis parallel to that of the pointer spindle. At one end of this plate is a quadrant engaging a pinion on the spindle which carries the pointer. A hair spring is fitted to the pointer spindle to take up any backlash in the mechanism (see Fig. 55).

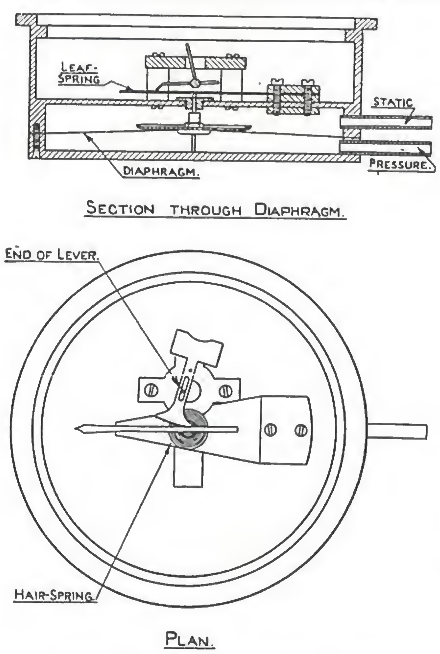

FIG. 55. DIAGRAM SHOWING CONSTRUCTION OF AIR SPEED INDICATOR GAUGE (DIAPHRAGM TYPE)

Fig. 56 shows a further type of air speed indicator which has a diaphragm box similar to an altimeter, the pressure pipe communicating with the inside of this elastic box. The pipe from the static side is led into the

(Figs. 54 and 55 from *A.P.* 1275, by kind permission of the Controller, H.M.S.O.)

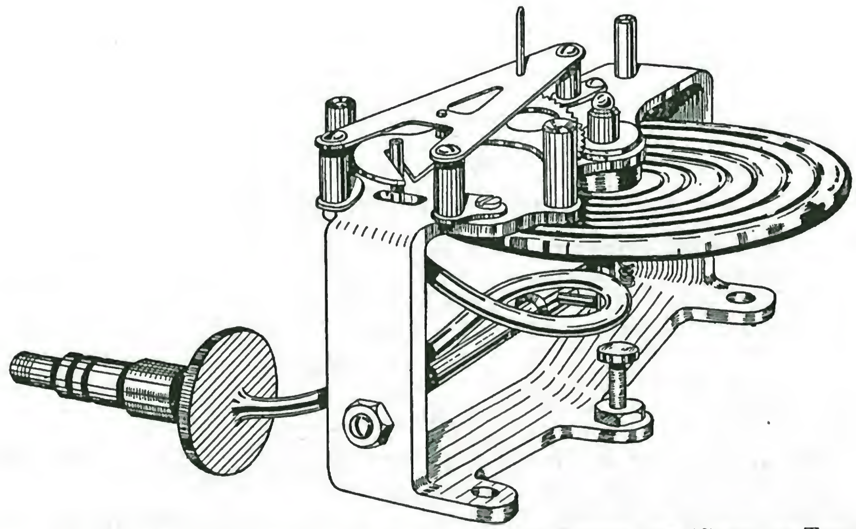

Fig. 56. Showing Construction of Air Speed Indicator (Capsule Type)

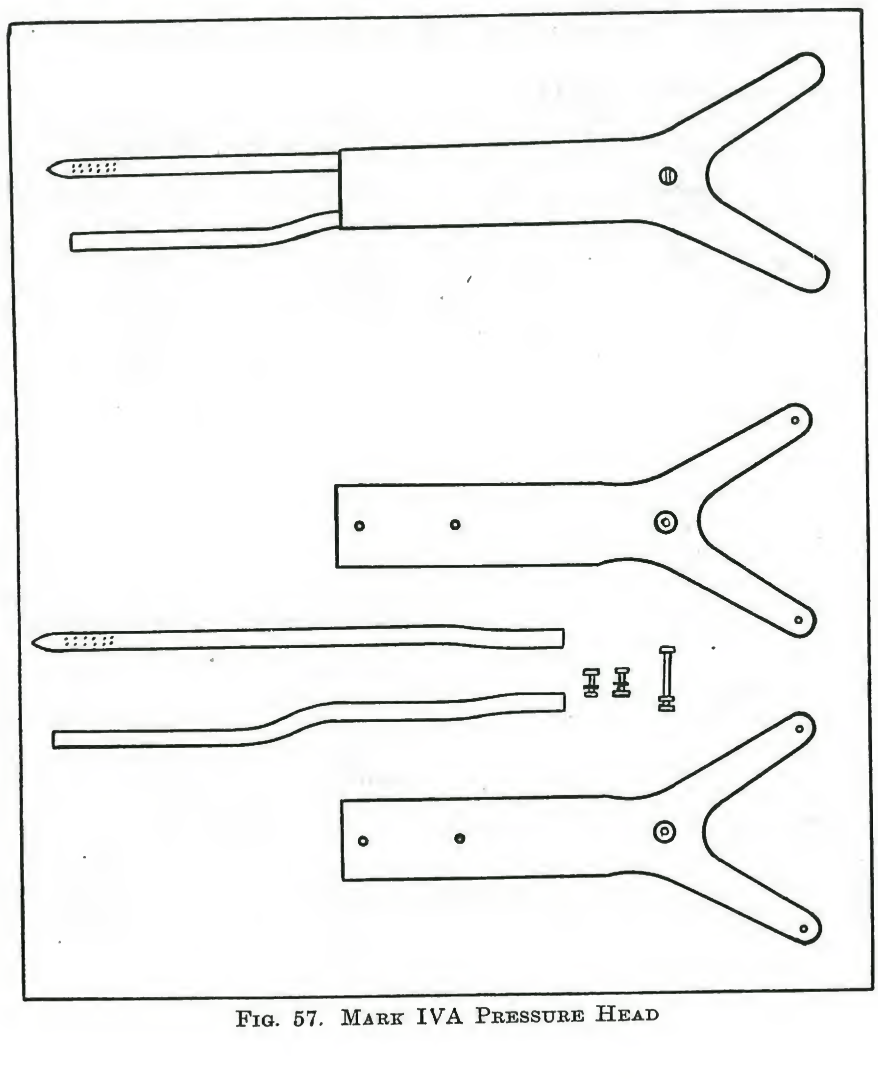

Fig. 57. Mark IVA Pressure Head

airtight case. The diaphragm box is held in a frame which also carries a transverse shaft having two short balanced arms mounted across it. The transverse shaft arms form a bell crank mechanism in which the two arms are considerably offset. One arm is coupled to the underside of the diaphragm or capsule, so that expansion or contraction of the latter results in rocking

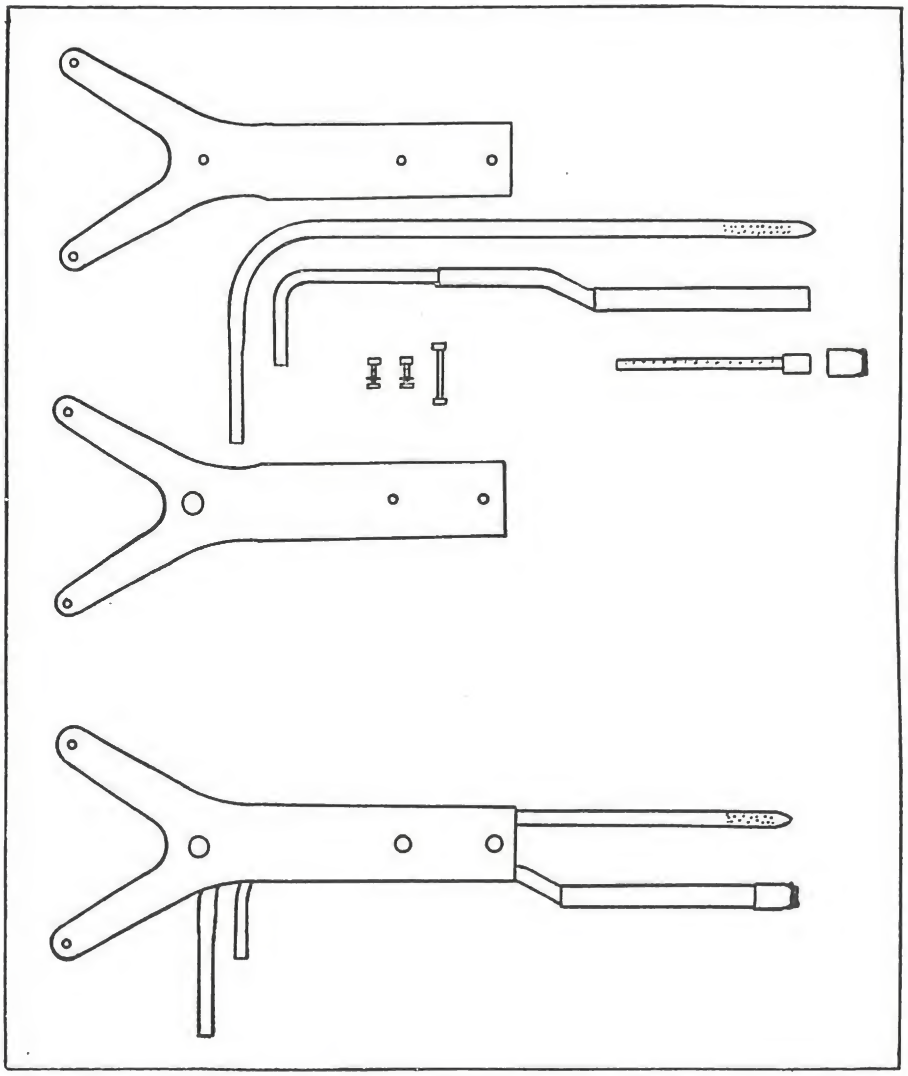

FIG. 58. MARK VA PRESSURE HEAD

the transverse shaft. The arm is cranked to pass through a hole in the top of the frame and engages in the slot of a toothed quadrant, meshing with the pinion of the pointer spindle. A hairspring is fitted to take up any backlash.

The Pressure Head. (Approved types: Mk. IVA and VA)

The Mk. IVA pressure head (Fig. 57) consists of a static tube with a closed pointer, the forward portion of the tube being perforated with a series of small holes. The pressure tube is open at the end.

The Mk. VA pressure head (Fig. 58) is generally the same as the IVA,

except that the pressure pipe has within it a tube closed at the back but open at the front end and drilled on its upper surface with a number of small holes which communicate with the inside of the larger pipe. The inner tube is located in the outer by a brass nipple soldered at the open end. The tube is prevented from rotating by flats on the nipple and the outer pipe. "Top" is stamped on the nipple to ensure correct assembly with perforations uppermost. A screwed nipple cap with an airtight joint fixes the inner in the outer tube.

With this pressure head the static tube is the higher placed of the two and has "top" stamped on it. The head was designed for use in tropical countries when trouble due to choking of the ordinary pressure tube by insects, etc., was met with. Care should be taken to keep the inner tube clean of any accumulations and the perforations clear. See that the word "top" is right way up on replacement.

The brass cap should be tightened with the fingers only to prevent straining the immediate installation.

Piping

The piping from the pressure head is of light alloy on landplanes and non-corrosive material or copper on seaplanes. The tubing joints and connections are made by rubber tubing or otherwise low-pressure couplings.

Graduation Marking of Instruments

The indicators on land aircraft are graduated in miles per hour; on seaplanes they are graduated in knots.

Installation and Maintenance

Owing to disturbances in the air current due to the reaction of parts of the aircraft and the slipstream of the tractor airscrew it has been found by experience that the best position for the pressure head is in front of an outer strut. On monoplanes the usual position for the pressure head is on an extension forward from the leading edge, or on a downward extension (about one-quarter of the wing chord) below the plane. The position in both cases is out towards the wing tip, beyond the influence of the airscrew slipstream.

It is important that all pressure heads should face the direction of flight. When more than one indicator is required on large aircraft the gauges are coupled up in parallel to one pressure head. To check for correct functioning let air be blown lightly down the pressure tube and hold the pressure at different stages while noting the indicator pointer. Should the pressure fall back rapidly check all the joints and pipe lines. Cases have been known where failure has been caused by corrosion eating holes through the piping.

Inspect the pressure head for damage and see that the edge of the opening of the pressure tube is smooth and round, also that the small holes in the static tube are clear. The static system should be checked by clipping a rubber tube beyond the rearmost of the small holes and applying suction instead of blowing as in the case of the pressure side. The rubber tubing should in this case be so arranged as to allow a concentric space between it and the static tube.

Testing

The air speed indicator may be tested by connecting it up in parallel with another air speed indicator of known accuracy. Portable calibrators

(Figs. 59 and 60) are also available. These provide a portable standard against which the accuracy of air speed indicators may be checked. The scale is graduated to read direct air speeds. Air pressure is supplied to both the manometer and indicator under test, and comparison is made between the readings. The permissible tolerance is approximately $\pm$ 3 m.p.h.

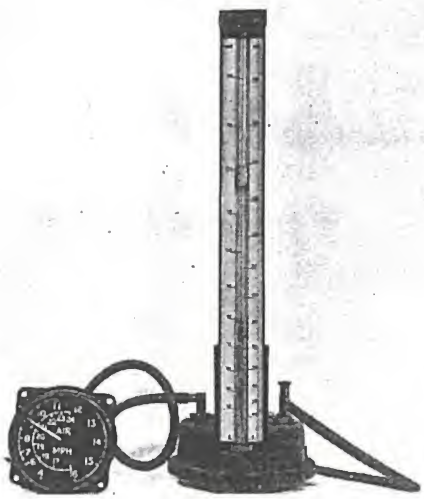

FIG. 59. AIR SPEED INDICATOR UNDER TEST (READING M.P.H.)

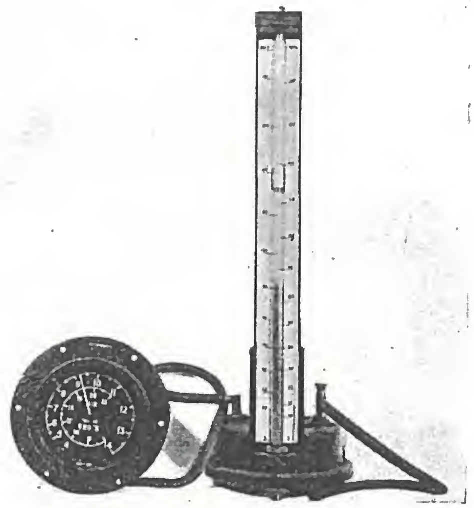

FIG. 60. AIR SPEED INDICATOR UNDER TEST (READING KNOTS)

17. ALTIMETER

(Approved types: Mk V, Mk VA, Mk VB)

Altimeters are instruments for indicating the height of the aircraft. These instruments are similar in construction to the aneroid barometer and measure the pressure of the atmosphere, but unlike the barometer, the dials are calibrated to read height direct. This height is, however only approximate, as the accurate determination of height is not easy, necessitating an exact knowledge of air temperatures as well as pressures. The Mk. V series instruments are calibrated in accordance with the "Isothermal Law" (i.e. the temperature of the air is assumed to be constant at all heights).

The diaphragm box is round and flat with corrugated sides, airtight and from which air has been exhausted. One side of this box is connected with the base plate, and the other to the end of the leaf spring. A change of pressure causes the diaphragm to move, and the spring moves together with the diaphragm. This small movement is magnified by means of a long connecting lever, a bell crank lever, a chain, drum, and spindle. The pointer is attached to the spindle and a hairspring is fitted to overcome any back lash (see Fig. 61).

The pointer moves over a height scale on the dial. The dial is operated by a milled knob attached to a pinion, and before each flight the milled knob should be turned to set the zero on the dial in line with the pointer. When the altimeter is installed the dial should be as near vertical as possible with the milled knob at the bottom. The instrument should be mounted so as to be unaffected by vibration.

Testing

(Suitable apparatus: Mk. I portable type calibrator and a standard altimeter Mk. IIID.)

Altimeters are tested in a cylinder, the air being exhausted by means

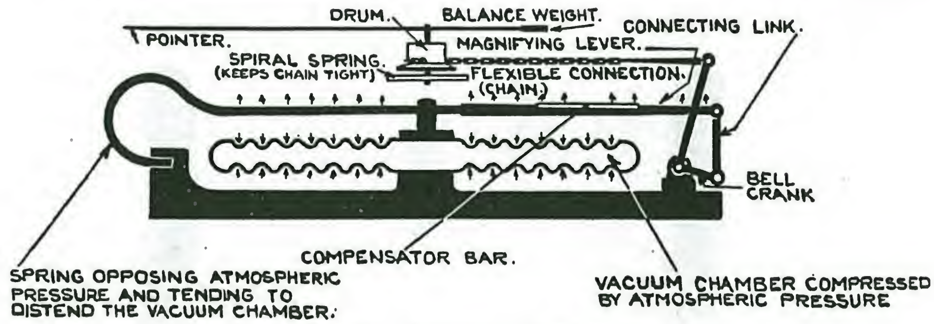

FIG. 61. ANEROID ALTIMETER

of a vacuum pump. The cylinder is fitted with guide slots, and the instrument to be tested is placed inside the chamber together with a standard altimeter Mk. IIID. Adjust the pointer on the altimeter until it corresponds to the standard gauge, then exhaust the air until the pointer on the standard gauge reads 1,000 ft., and so on at the rate of 1,000 ft. per minute, the readings on the altimeter under test being noted and compared with

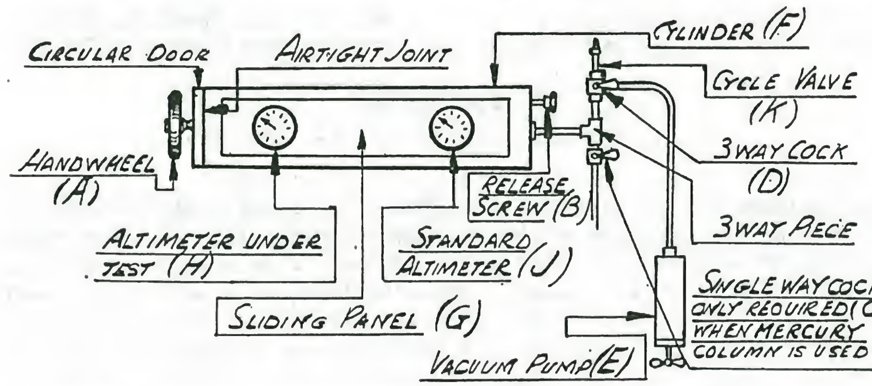

FIG. 62. DIAGRAM OF TESTING INSTALLATION FOR ANEROID ALTIMETER

the standard Mk. IIID. When this test is completed, allow air to enter the chamber through a release screw, thus increasing the pressure, and note the reading at each 1,000 ft. during descent.

The principle of the Mk. I portable type calibrator is shown in diagrammatic form in Fig. 61.

Sequence of Operation

1. Remove circular door by releasing hand wheel (*A*).
2. Tighten up release screw (*B*).
3. Close cock (*C*).
4. Turn cock (*D*) to couple pump (*E*) to cylinder (*F*).

(Fig. 61 from A.P. 1234, by kind permission of the Controller, H.M.S.O.)

5. Draw out sliding panel (*G*) and fit altimeter (*H*) and (*J*); at the same time set altimeter (*H*) to correspond with standard (*J*).

6. Replace panel and close door by hand wheel (*A*).

7. If standard instrument is below zero, slightly exhaust cylinder (*F*) by pump (*E*).

8. If standard instrument is above zero attach small pump to cycle valve (*K*) and pump slight positive pressure into cylinder.

9. Close cock (*D*) and proceed with test already described.

18. TURN INDICATOR

Approved types for civil aircraft are—

Reid.	Reid-Sigrist.
Sperry.	S. G. Brown Type E.
Schilovsky-Cooke.	S. G. Brown Venturi Type A.
Mechanism, Ltd.	Mark 1.A.
Pioneer No. 385.	Mark 1.B.

A brief description follows of the latest type turn indicator—Mk. 1 (Reid and Sigrist). This indicator employs an air-driven gyroscope

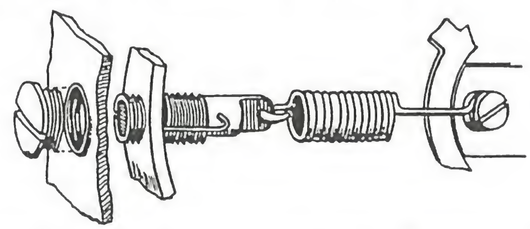

FIG. 63. SPIRAL SPRING AND SCREW FOR ADJUSTING TURN INDICATOR SENSITIVITY

mounted in a horizontal gimbal ring, the axis of the gyroscope being athwart the aircraft and the axis of the gimbal ring fore and aft. When the aircraft turns, the movement corresponds to rotation of the instrument in a horizontal plane, and a precessing torque is applied to the gimbal ring to turn. The gimbal ring, being spring controlled, comes to rest in a position of equilibrium when the precessing torque balances the tension in the spring. The movement of the gimbal ring, suitably damped, is indicated by means of a pointer on the scale in the front of the instrument. A second pointer on the scale, giving a cross-level indication, is actuated through a gearing device by a pendulum, the pointer moving in the direction of tilt.

A spiral spring, the tension of which may be adjusted, is attached between the gimbal and spider (see Fig. 63) and serves to control the sensitivity of the instrument.

Access to the adjusting screw is obtained through a hole drilled in the side of the case. Insert a screwdriver into the hole and give the inside screw a slight turn anti-clockwise, according to whether less or more sensitivity is required. One complete turn in this direction is usually sufficient.

Installation of Instrument in Aircraft

It is essential to have the instrument correctly fitted to the pilot's dashboard. The aircraft should be in the flying level position and the

top needle on the zero mark (see Fig. 64) before placing the screws in position.

Fit the venturi (see Fig. 65) in the slipstream as near the dashboard as possible, and connect to the instrument, using light alloy metal tubing

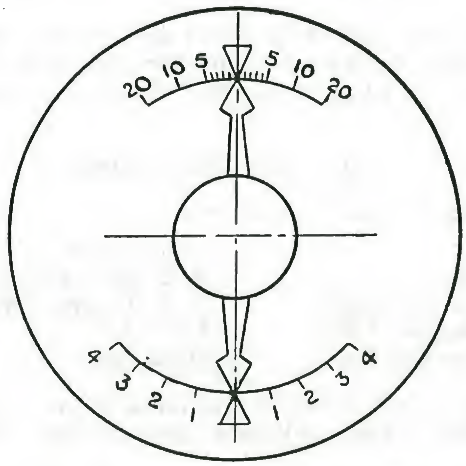

FIG. 64. TOP NEEDLE WITH RELATION TO ZERO MARK, TURN INDICATOR

and low-pressure metal couplings, or a piece of pressure rubber tubing. Care should be taken to fit the venturi in the best position. If the aircraft is fitted with an air-cooled engine, fit on or near the exhaust pipe; on water-cooled engines the venturi can be fitted behind the radiator, so that the warmth from the engine will prevent the tube becoming frozen, no matter

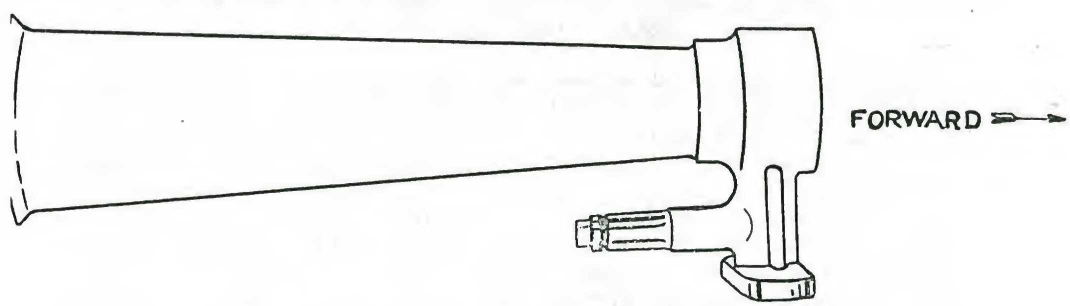

FIG. 65. INSTALLATION OF TURN INDICATOR VENTURI

at what altitude the aircraft is flown. When the venturi is in position the small end must be in front, facing the line of flight.

The Gyro Rotor Unit (Reid and Sigrist)

The principle of the air-driven turn indicator is shown in Fig. 66.

(*a*) The position of the unit when the instrument is running normally, that is, when the aeroplane is flying a straight course.

(*b*) The position of the different components when the gyro needle is indicating a rate of turn to the left, the action being as follows—

The gyro is spun by the inlet of air through the jet and precesses clockwise on the end bearings, the amount of precession being controlled by

the spring. The needle is moved by the gearing, so that its indication is twice the angular amount of the gyro precession.

(c) The position of the unit when the gyro needle is indicating a turn to the right.

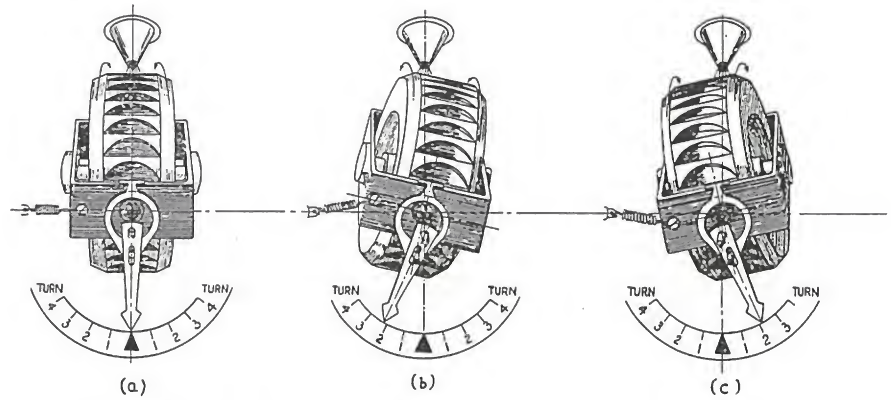

FIG. 66. TURN INDICATOR GYRO ROTOR UNIT

Maintenance

The instrument should be examined occasionally to see that the air connection is airtight, and that the nozzle of the case is screwed up so that no leaks occur. Clean the dust cap, and remove the top cap nozzle and the double gauze filters.

To do this the three small screws in the top cap of the inlet nozzle should be removed, and the double gauze filters taken out, cleaned, and replaced. At the same time the inside of the tube should be cleaned and the neck examined to see that no dust from the engine has accumulated around it. No attempt should be made to dismantle this instrument. If a fault develops, the instrument should be returned to the makers for overhaul.

19. COMPASS INSTALLATION IN AIRCRAFT, AND ADJUSTMENT

I. Inspection before installation.
II. During installation.
III. Coefficient A.
IV. Coefficient B.
V. Coefficient C.
VI. Sequence of swinging.
VII. After adjustment.

(I) Inspection Before Installation

(a) Inspect compass for damage in transit.

(b) Inspect for freedom from pivot friction. The compass should be in a level position; note the reading; by the use of a magnet deflect the compass needle through about 10°, remove the magnet and if the compass magnet system returns to its original position when the bowl is tapped with the finger the compass may be considered free from pivot friction.

(c) Inspect for freedom from discoloration of the card, bowl, liquid, or window. The compass must be sufficiently clear to enable the pilot to read under normal flying conditions.

(*d*) Inspect the anti-vibrational devices; moving parts must be inspected for condition.

(*e*) See that the bowl is completely filled with approved liquid, and if even small bubbles appear add more of the approved liquid until all bubbles disappear.

II. During Installation

(*a*) The compass should be handled carefully and must not be subjected to shocks.

(*b*) Mountings should be of non-magnetic material and securing screws should also be of non-ferrous or other non-magnetic metal.

(*c*) With the aircraft in rigging position the compass should be horizontal (or vertical according to type).

(*d*) The lubber line must be forward and be parallel with the fore and aft centre line of the aircraft.

(*e*) The corrector box must be fitted below the centre of the compass with one set of magnet holes fore and aft.

(*f*) All removable and fixed equipment must be in the correct position before swinging the aircraft for compass adjustment.

Analysis of Deviation

III. Coefficient A

All the iron and steel parts and equipment of an aircraft are magnetic to some extent, and each individual part in the neighbourhood of a compass tends to cause deviation. It would be impossible to compensate separately for the effect of each individual part, but fortunately this is not necessary. All the possible magnetic effects in an aircraft can be resolved into five distinct types which are called the approximate coefficients, and are distinguished by the five capital letters A to E. The deviation coefficients D and E will be ignored here as no provision is made in any modern compass for corrections. It is necessary to know how to calculate the coefficients and how to correct for them. The necessary rules are given below, the calculations being based on the following deviation table—

Magnet	Compass	Deviation
N. (0°)	350°	+ 10° (E.)
N.E. (45°)	39°	+ 6° (E.)
E. (90°)	91°	− 1° (W.)
S.E. (135°)	140°	− 5° (W.)
S. (180°)	186°	− 6° (W.)
S.W. (225°)	228°	− 3° (W.)
W. (270°)	261°	+ 9° (E.)
N.W. (315°)	301°	+ 14° (E.)

The effect of coefficient A is to cause the same deviation on all courses. Coefficient A may be set up by—

(i) An unusual distribution of soft iron in the craft;

(ii) The incorrect mounting of the compass (lubber line slewed out of its correct position); or

(iii) The incorrect mounting of the card upon the magnet system (card error).

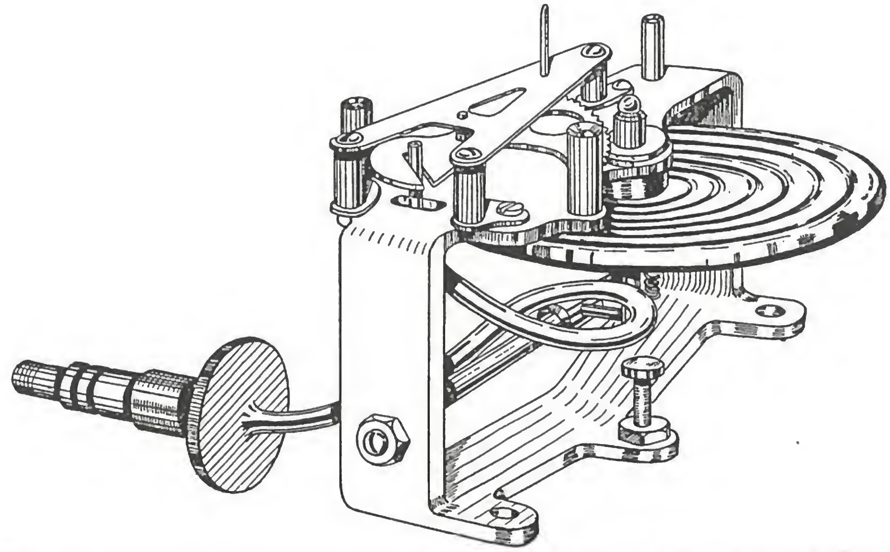

Fig. 56. Showing Construction of Air Speed Indicator (Capsule Type)

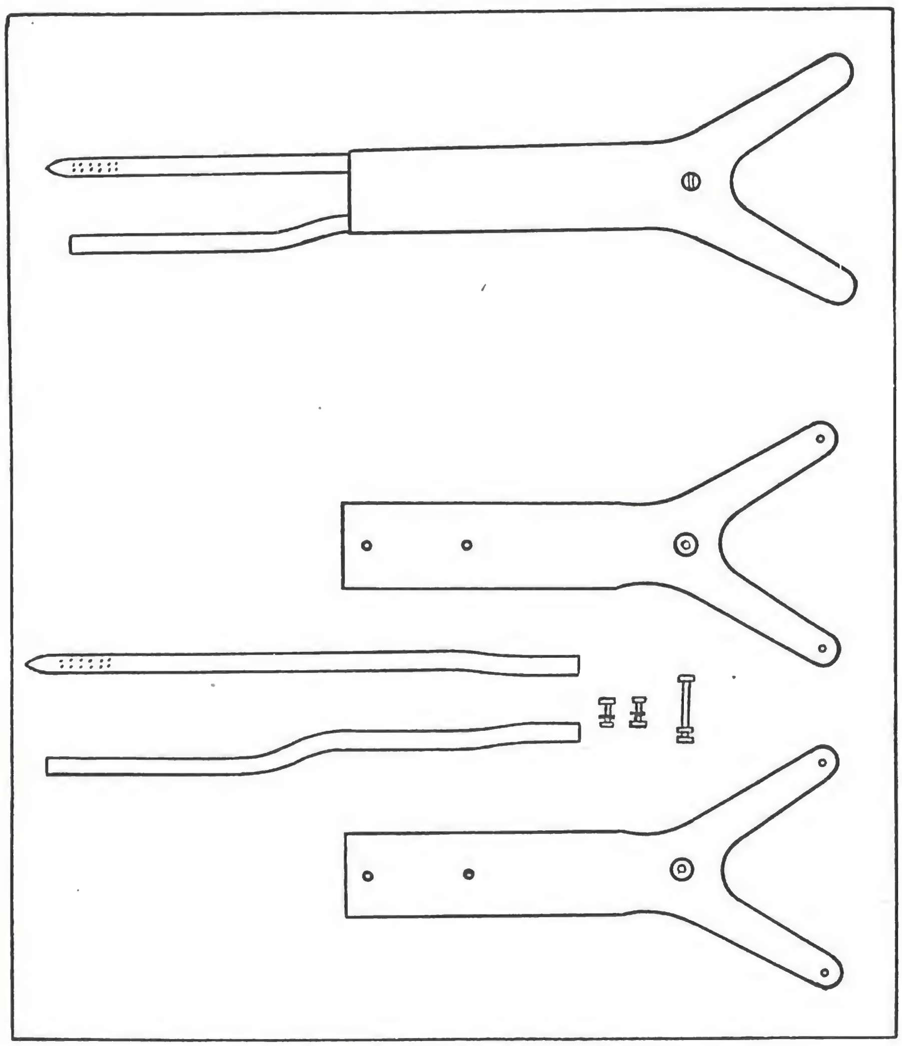

Fig. 57. Mark IVA Pressure Head

CHAPTER IV

INSTRUMENTS

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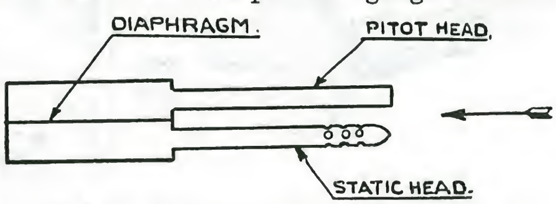

FIG. 54. AIR SPEED INDICATOR DIAGRAM

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Of the two most common forms of construction, one consists of an airtight chamber divided into two compartments by means of a diaphragm. The pitot head is connected to one compartment and the static head to the other. Any change in the pressure in either compartment causes the movement of the diaphragm, which is recorded on the dial by means of a pointer. A disc with a spindle working in a guide is attached to the centre of the diaphragm; as the diaphragm moves the end of the spindle presses against a leaf spring which is deflected in proportion. The leaf spring actuates a bell crank lever, one arm of which projects through a slot in a metal plate pivoted on an axis parallel to that of the pointer spindle. At one end of this plate is a quadrant engaging a pinion on the spindle which carries the pointer. A hair spring is fitted to the pointer spindle to take up any backlash in the mechanism (see Fig. 55).

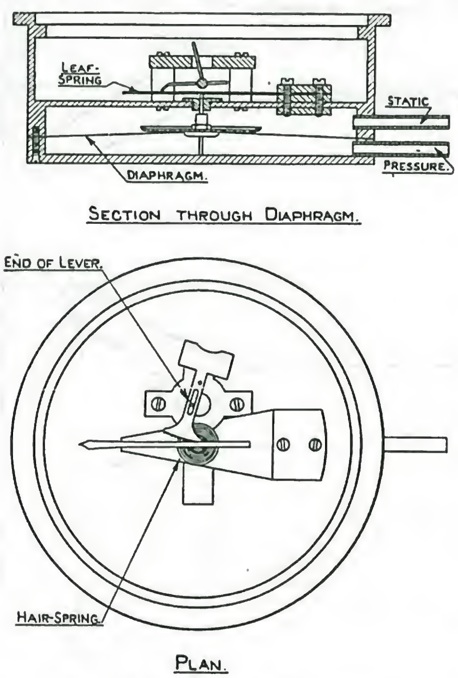


FIG. 55. DIAGRAM SHOWING CONSTRUCTION OF AIR SPEED INDICATOR GAUGE (DIAPHRAGM TYPE)

Fig. 56 shows a further type of air speed indicator which has a diaphragm box similar to an altimeter, the pressure pipe communicating with the inside of this elastic box. The pipe from the static side is led into the

(Figs. 54 and 55 from *A.P.* 1275, by kind permission of the Controller, H.M.S.O.)

In the first case the coefficient is known as "real A" and in the other two "apparent A." Coefficient A is calculated by the following formula

$$A = \frac{\text{Sum of 8 deviations on N. N.E. E. S.E. S. S.W. W. N.W.}}{8}$$

To calculate A from the deviation given above

$$A = \frac{+10 + 6 - 1 - 5 - 6 - 3 + 9 + 14}{8} = \frac{+39 - 15}{8} = \frac{+24}{8} = +3^\circ$$

Whether A be real or apparent the method of correction is the same. To correct $+A$, turn the compass bowl round clockwise. To correct $-A$, turn the compass bowl round anti-clockwise. Hence, since the value of A in the example is $+3^\circ$, the method of correcting would be to loosen the bolts holding the compass, turn it 3° clockwise (reading the 3° from the compass) and then secure the instrument again.

IV. Coefficient B

This may be considered as due to an imaginary magnet lying in the fore and aft line of the machine. The maximum effects are found on magnetic east and west.

Coefficient B is obtained from the formula

$$B = \frac{\text{Deviation on east} - \text{deviation on west}}{2}$$

To calculate B from the example—

$$B = \frac{-1 - 9}{2} = \frac{-10}{2} = -5^\circ$$

Notice that the sign of deviation on west is changed from + to –. The sign of a deviation must always be changed when the sign (–) precedes the deviation in the formula (algebraic subtraction). The rules for correcting B are—

To correct $+B$, use fore and aft magnets with red poles forward.
To correct $-B$, use fore and aft magnets with blue poles forward.
Correction is carried out when the craft is heading east or west.

To correct for B of -5°, insert magnets in the fore and aft tubes in the corrector box, blue poles forward, until the compass reading changes by 5° as nearly as possible.

V. Coefficient C

The effect of this is similar to that of a magnet lying athwartships in the aircraft. The maximum effects are found on magnetic north and south.

The formula for calculating coefficient C is

$$C = \frac{\text{Deviation on north} - \text{deviation on south}}{2}$$

To calculate C from the example

$$C = \frac{+10 + 6}{2} = \frac{+16}{2} = +8^\circ$$

The rules for correcting for coefficient C are—
To correct $+C$, use athwartships magnets with red poles to starboard.
To correct $-C$, use athwartships magnets with blue poles to starboard.

The correction is carried out when the aircraft is heading north or south. The correction in the example would consist of inserting magnets in the athwartships tubes with red poles to starboard until the compass reading changed by 8°.

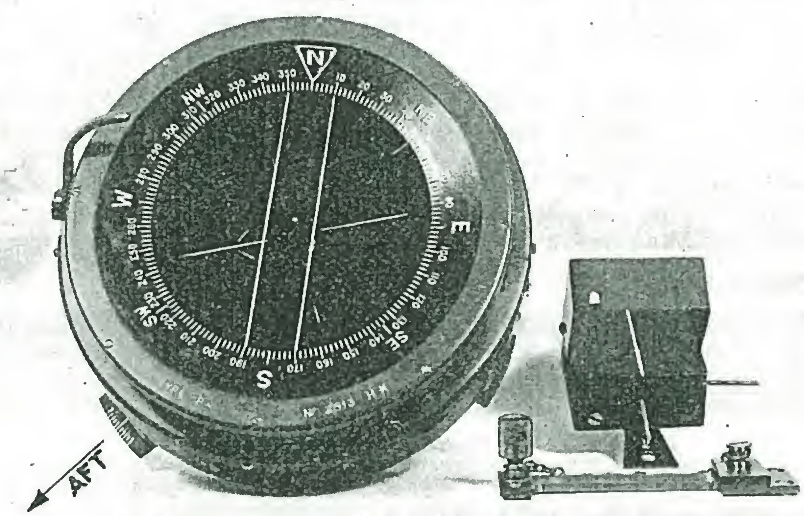


FIG. 67. P.4 COMPASS WITH CORRECTOR BOX DETACHED SHOWING MAGNETS PARTIALLY WITHDRAWN

VI. Sequence

Adopt a definite sequence when swinging any aircraft. A sequence is given here which may be simply followed. If more than one compass is fitted in the aircraft corrections to all compasses must be made before the aircraft is moved.

(*a*) Place the aircraft on magnetic N. Align it carefully; put the aircraft and its controls in flying position. Enter the compass reading in log book.

(*b*) Place the aircraft on E. Enter compass reading.

(*c*) Place the aircraft on S. Enter compass reading.

(*d*) Calculate and correct for coefficient *C*.

Calculations of coefficients and corrections made.

To calculate coefficient *C*.

Deviation on N. = $-3°$; on S. = $+5°$.

Then $C = \frac{-3-5}{2} = -4°$.

To correct for coefficient *C*.

Insert magnets athwartships with blue poles to starboard until compass reading changes 4°—i.e. until compass reads 179°.

VI. Sequence—(*contd.*)

(*e*) Enter corrected reading on S.

(*f*) Place the aircraft on W. Enter compass reading.

(*g*) Calculate and correct for coefficient *B*.

To calculate coefficient *B*.
Deviation on E. = + 6; on W. = − 7.

Then $B = \frac{+6+7}{2} = +6\frac{1}{2}°$.

To correct for coefficient *B*. Insert magnets fore and aft with red poles forward until compass reading changes by $6\frac{1}{2}°$. Suppose the nearest to this obtainable is 6°, then compass will read 271.

(*h*) Enter correct reading on W.

(*i*) Place the aircraft on N.W. Enter corrected reading.

Calculations of coefficients and corrections made.

(*j*) Place the aircraft on N. Enter corrected reading.

(*k*) Place the aircraft on N.E. Enter corrected reading.

(*l*) Place the aircraft on E. Enter corrected reading.

(*m*) Place the aircraft on S.E. Enter corrected reading.

(*n*) Place the aircraft on S.W. Enter corrected reading.

(*o*) Calculate coefficient *A* from corrected readings and correct for it if necessary.

To calculate coefficient *A*.
Deviations on the eight cardinal and quadrantal points after correction are—

+ 1, 0, 0, 0, + 1, −1 , −1, − 1,

Then $A = \frac{+2-3}{8} = -\frac{1}{8}°$ which is too small to attempt to correct.

EXAMPLE OF PARTICULARS ON COMPASS CARD

Adjustments made at . . . Southampton Aerodrome.
Date of Adjustment . . . 17/11/33.
Type of Aeroplane . . . "Goodflyer."
Registration of Aeroplane . . G–OXYZ.
Type of Compass . . . P.4.
Number of Compass . . . 8135.A.

	First Reading	Corrected Reading	Number and Disposition of Adjusting Magnets
N. (0°) . .	3 (*a*)	359 (*j*)	1 magnet 2/32 red to port.
N.E. (45°) . .		45 (*k*)	
E. (90°) . .	84 (*b*)	90 (*l*)	
S.E. (135°) . .		135 (*m*)	2 magnets 2/32 red for ward.
S. (180°) . .	175 (*c*)	179 (*e*)	
S.W. (225°) . .		226 (*n*)	
W. (270°) . .	277 (*f*)	271 (*h*)	
N.W. (315°)		316 (*i*)	

Adjustment made and Deviation Card fitted by—

Signature JOHN BROWN, G.E., No. A, 125.
Remarks Compass liquid slightly discoloured.

VII. After Adjustment of Compass

(*a*) Fasten the corrector box covers securely.

(*b*) Fill in a deviation card (both sides) for each compass in the manner shown in the above example and mount it near the appropriate compass.

Ascertaining Deviations by Landing Compass (Landplanes)

Any aircraft can be swung as accurately by landing compass alone as by means of a swinging base (and in the case of large machines often more quickly). The aircraft should be set up in the open, at least 40 yards away from any considerable masses of iron, such as hangars, railway lines, etc., or 150 yards from an electric or W/T generating station, and the site chosen should be free from local magnetic effects.

Plumb lines should be suspended from the centre of the nose of the aircraft and the centre of the stern, and the landing compass should be set up in line with these and approximately 40 ft. in the rear of the aircraft. By sighting carefully through the slot and hair line of the landing compass on to the suspended plumb lines the correct magnetic heading of the aircraft can be read on the landing compass through the prism fitted thereto. The difference between this reading and that shown by the aircraft compass indicates the amount of error in the latter (i.e. the deviation) on any particular bearing. Successive readings are taken by swinging the aircraft about a fixed pivot point and by moving the landing compass round at a fixed radius from the same point, lining up always with the two plumb lines. It is not necessary to line up the aircraft "dead on" the desired bearing. A maximum error of 4° is permissible provided the error as shown by the bearing compass is added to or subtracted from the aircraft compass reading as necessary in order to deduce what reading the latter compass would have given if the aircraft had been aligned accurately. For example, if the aircraft compass shows 85° when the landing compass shows 88° it may be assumed that the aircraft compass would have shown 87° when the aircraft was correctly aligned on the 90° bearing. The method of correcting errors in the aircraft compass has already been dealt with.

Swinging an Aircraft Afloat

As a general rule the compass of an aircraft should not be corrected when it is afloat, as even under the most favourable conditions the degree of accuracy easily to be obtained from swinging ashore can scarcely be obtained. It is occasionally necessary or convenient to check the deviations while the aircraft is afloat, and of the various methods two will be briefly described.

The swinging is normally carried out while the aircraft is moored to a buoy. The essential problem is to determine the correct magnetic course of the aircraft at a given moment. One method is to take bearings of a distant object, preferably by bearing compass or from a bearing plate. An object should be selected at a suitable distance and its magnetic bearing from the buoy should be determined from a chart.

As a rough guide it may be mentioned that if the selected object be 3 miles distant from the buoy and the aircraft can move round a circle of 20 yards diameter, the maximum change of bearing due to alteration of the position of the aircraft will be of the order of $\frac{1}{4}$°. Suppose the object selected be a lighthouse—L in Fig. 68—and the magnetic bearing of L from the buoy B is 30°. Then suppose that a bearing of L is found to be 34° by bearing compass from the aircraft at a moment when the course of the aircraft, by the bearing compass, is 70°. If C be the bearing compass, it is seen that the direction CL is given as 34° by the instrument

when actually its direction is 30°. It follows that a deviation of $-4°$ exists, and this is the deviation on a course of 70° by compass. Hence, the magnetic course of the aircraft when the bearing was taken was 66°. It should be noticed that, if MM_1 represent the magnetic meridian, the bearing compass measures the angle MCL (plus or minus the angle of deviation), according to whether the deviation is westerly or easterly.

Considering now the use of a bearing plate, suppose P in Fig. 69 represents the bearing plate, and C the pilot's compass. The bearing plate must be fixed in the aircraft so that its lubber line lies in or parallel to the centre line of the aircraft, and it must be clamped with zero registering against the forward lubber line. Readings should be taken from the foresight of the instrument.

Suppose the bearing of L is found to be 324° and simultaneously the course by compass is 70°. If CPB be the centre line of the aircraft, the compass measures (inaccurately if there be any deviation) angle MCB.

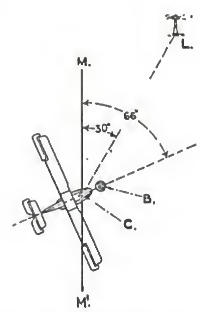


FIG. 68. SWINGING AN AIRCRAFT AFLOAT BY BEARING COMPASS

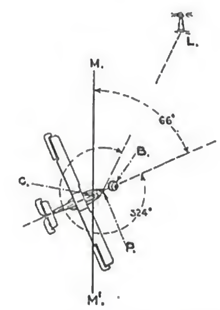


FIG. 69. SWINGING AN AIRCRAFT AFLOAT BY BEARING PLATE

The bearing plate measures angle BPL accurately. Then the sum of these angles (subtracting 360° from the sum if necessary) is the bearing of L from the aircraft by compass; $324° + 70° = 394°$; $394° - 360° = 34°$. As the correct magnetic bearing is 30°, there is a deviation of $-4°$ on a compass course of 70°, or a magnetic course of 66°. Thus, the same result can be obtained from a bearing plate and steering compass as from a bearing compass.

It may happen that it is not convenient to take bearings in the manner outlined above. An alternative method is to mount a landing compass ashore on a site free from local magnetic fields and simultaneously to take bearings of the bearing compass or bearing plate in the aircraft from the landing compass and of the landing compass from the aircraft. It should be obvious from consideration of Figs. 68 and 69 that if L be supposed to represent a landing compass, and the bearing of the aircraft was 210° from the landing compass, then by taking the reciprocal of 210° (i.e. 30°) as the correct magnetic bearing of L from the aircraft the deviation can be obtained.

How in practice to swing an aircraft afloat can scarcely be usefully laid down, as so many various circumstances arise which may prohibit the adoption of any particular method. The vagaries of tide and wind, the number of the crew and amount of time available all require consideration. A few general remarks, however, may be made. If a motorboat is available it will provide a convenient way of turning the aircraft round the buoy. In very favourable conditions, it may be possible to hold the aircraft steady on a particular course for a short time; when these

conditions obtain, the aircraft may be headed approximately on a cardinal or quadrantal point by reference to one of its own compasses. Usually, however, it will not be possible to hold the aircraft steady on any course for an appreciable time. It is then advisable to take a large number of bearings—say, one for every 12° or 15° of alteration of the aircraft's course. A curve should be plotted for the results obtained and a deviation card

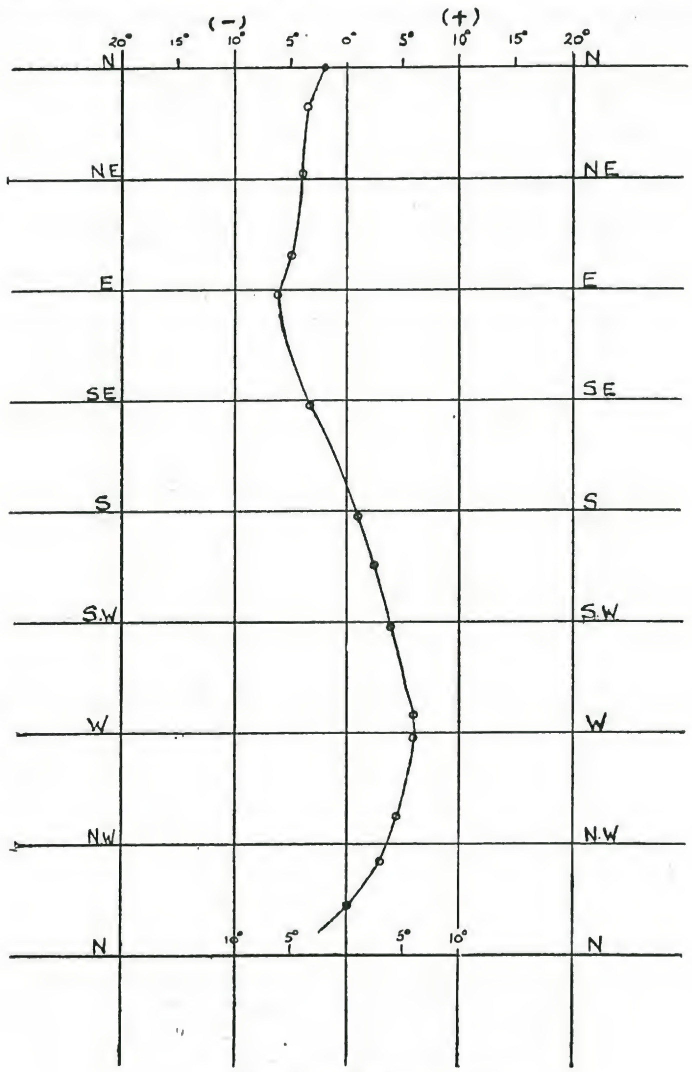


FIG. 70. CURVE OF COURSES

filled up from the curve. When it is necessary to take bearings, etc., as the aircraft is moving—even though the movement is slow—it is essential to good results that all observations be taken at the same time. Thus, suppose the bearing of a distant object be taken by bearing compass, one observer will be required to read the bearing and another the course from the bearing compass, while one observer is stationed at each of the other compasses in the aircraft. As the bearing is taken a pre-arranged signal should be given, all observations taken at once and immediately noted

down. If reciprocal bearings of a landing compass are being used, a clear code of signals between the shore and the aircraft must be devised.

The results of an actual swing of an aircraft afloat are now given in full. The aircraft was swung in a tidal river under adverse weather conditions by an experienced compass adjuster. Mist prevented observations of a distant object and no bearing compass was available. A prepared form was used as given in the following table.

	(1) Course by Pilot's Compass	(2) Bearing by Bearing Plate	(3) Sum of Cols. (1) and (2)	(4) Landing Compass Reciprocal	(5) Deviation
(274) .	268	48	316	322	+ 6
(296) .	291	26	317	322	+ 5
(321) .	318	2	320	323	+ 3
(332) .	332	354	(686) 326	326	0
(352) .	355	336	(691) 331	328	− 3
(16½) .	20	308½	328½	325	− 3½
(44) .	48	282	330	326	− 4
(78) .	83	249	332	327	− 5
(94) .	100	233	333	327	− 6
(136) .	139	189	328	325	− 3
(181) .	180	141	321	322	+ 1
(207½) .	205	113½	318½	321	+ 2½
(229) .	225	91	316	320	+ 4
(264) .	258	60	318	324	+ 6

The sum of Cols. (1) and (2) gives the equivalent to the bearing of the landing compass taken from the pilot's compass in the aircraft. Column (5) shows the deviation for the courses by compass in Col. (1). The magnetic courses corresponding to these compass courses were obtained; these are given in brackets on the left of the form. The curve shown in Fig. 70 was then plotted and the entry on the deviation card made as follows—

For Magnetic Course		Steer by Compass
N.	0	2°
N.E.	45	49°
E.	90	96°
S.E.	135	138°
S.	180	179°
S.W.	225	221°
W.	270	264°
N.W.	315	312°

(Certain of the text and data appearing on pages 64–71 have been extracted from *A.P.* 1234, by kind permission of the Controller, H.M.S.O.)

CHAPTER V

GENERAL SERVICE ELECTRICAL INSTALLATION INCLUDING CONTINUITY AND INSULATION TESTS

20. THE GENERATOR

Aircraft generators comprise various types of dynamic electric machines which, although of small output, are highly specialized in their characteristics and represent the latest development of light-weight design and manufacture. The generator is usually arranged for windmill (as here first considered) or sometimes for engine, drive (as secondly described).

Air-driven Generator

A typical air-driven aircraft generator (bi-polar type) complete with cable plug (see Fig. 71) is here described. It is direct current shunt wound for an output of 500 watts at 12 to 14 volts D.C. when running at a speed of 4,500 r p.m.

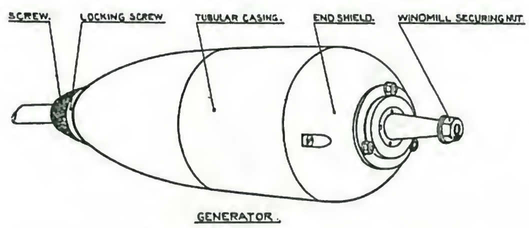


Fig. 71. Generator

The body of the generator consists of an aluminium external tubular casing, with the field yoke fitted inside. The poles are formed integrally with the field yoke which is built up of laminated stampings. The field coils are laid round the pole pieces before the field is fitted into the external casing, the coil-overhang being taped up and varnished.

The aluminium end shield incorporates the front ball bearing which is designed to take the windmill thrust. The bearing is protected in front by a steel washer and an internal watertight gland, a second washer closing the bearing housing inside the end shield. Three screws are provided to bolt the two washers together and also secure the bearing to the end shield; the latter is fixed to the body of the generator by two bolts which pass through clearance holes in the field laminations and screw into the rear portion of the aluminium casing, the arrangement being such that the complete generator armature is withdrawn together with the front end shield. The forward end of the armature shaft is tapered to receive the windmill which is secured by a hexagon nut.

The armature core is built up of laminations and has twelve semi-closed slots in which the armature coils are laid, the slots being closed by fibre wedges which are driven in to secure the windings against centrifugal stresses. For the same reason, the end connectors and coil-overhangs are each bound with a layer of fine piano wire suitably insulated so as to prevent damage to the armature coil insulation.

The commutator is located at the rear end of the generator and has 36 segments. The rear portion of the generator, with spinning removed, is shown in Fig. 72.

The brush holders consist of two aluminium bridge pieces, which are secured to the bearing bracket by two bolts and are insulated from the brackets by flanged ebonite bushes through which the bolts are passed,

the flanged portions being on the brackets, while the nuts are insulated from the bridge pieces by mica washers. Two carbon brushes of rectangular cross section are mounted in each brush holder, the flexible leads being attached to the upper portion of each brush, which is copper-plated. Each brush is held in firm contact with the commutator by means of a pivoted arm, the extremity of which bears on the top of the brush, the bearing pressure being provided by small compression springs. The rear end of the generator is enclosed and protected by an aluminium spinning of streamline shape. The rear journal bearing is housed in the boss, which is formed between and cast integrally with two channel section arms forming an extension of the generator casing as shown in Fig. 71 above. A shoulder is formed at the rear end of the boss extension, the extremity being threaded to receive a locking screw. The end spinning fits over the threaded portion and is clamped between the shoulder on the boss and the locking screw. The connections to the generator are led in through a

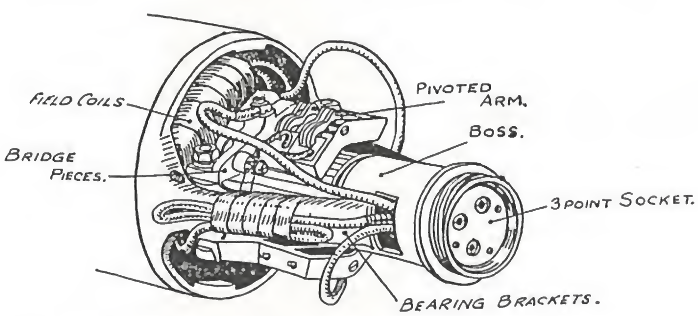


FIG. 72. GENERATOR WITH REAR SPINNING REMOVED

3-point plug and socket connection which is housed in the extreme aft portion of the generator.

The threaded portion of the boss is drilled and threaded internally, the 3-point socket being fitted and retained in the boss by a locking ring. The connections to the socket are soldered to tags brought through the back of the socket, connecting up being carried out before the socket is fitted; the 3-point plug is retained in position in the socket by a knurled screw which engages in the internally threaded portion of the boss.

The internal leads are brought out from the back of the socket through a rectangular aperture cut in the boss as shown. One lead is connected to each brush holder and the third permanently connected to the generator field. The leads are identified by coloured braiding, the colour for the lead to the positive brushes being yellow, the negative blue, and the field slate. The corresponding connections on the plug and socket are identified by sunken marks of yellow, blue, and slate.

The wiring diagram of the generator is shown in Fig. 73. The generator operates in conjunction with a voltage box. The external generator leads are connected to the yellow, blue, and slate terminals on the control box, a suitable resistance or field shunt being connected in parallel with the generator field as shown in diagram (Fig. 74).

When a 12-volt accumulator is charged from such a generator as here described, in conjunction with a voltage control box, the battery will be charged on the "constant voltage system," therefore the initial charging current when the battery is discharged may be three or four times the normal charging rate for the particular battery in use. This heavy current

only continues for a short time, however, and will not damage the accumulator. The charging current will fall steadily as the accumulator becomes charged, being practically zero when the fully charged state is reached.

Aircraft generators are designed with a minimum of copper and iron in order to reduce weight, and the temperature rise on continuous load of such machines is thereby much greater than in normal generator practice.

The reduction in weight output ratio is rendered possible by the extremely favourable conditions of cooling when the generator runs in the unobstructed slipstream of the aircraft's airscrew. If an aircraft generator is run on load on the ground for a lengthy period it will tend to overheat unless provision is made for cooling—the machine should therefore be run on the ground, with reduced load or cooled with a suitable air blast.

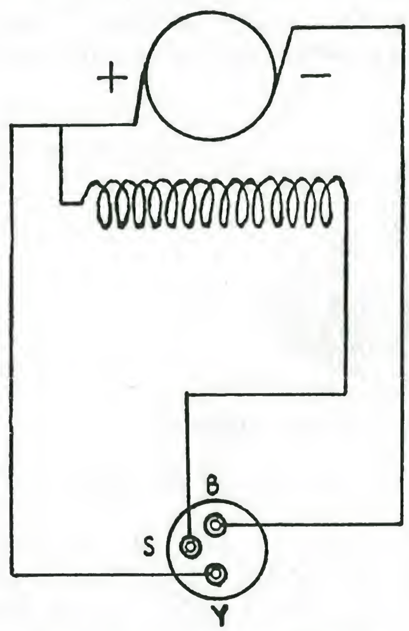


FIG. 73. GENERATOR WIRING DIAGRAM

Generators are manufactured to such specifications as will secure interchangeability of parts and give the required performance. In general, the generator is required to give a continuous output at full rating. In certain cases the generator is designed to take full advantage of the slipstream for cooling purposes, and the load run is then limited by the specification to half an hour. The normal fall of current due to temperature rise is compensated for by adjustment of the field regulator to maintain constant load. On conclusion of the load run the commutator is carefully examined. Any generator of which the commutator shows signs of pitting is rejected. Blackening of the commutator is slight and even all round the periphery; regularly spaced blackened segments alternating with bright segments are indicative of incorrect adjustment of the brushes or inherent bad commutation.

An overload 25 per cent in excess of the usual full load is customarily imposed.

The specification limits the speed at which the full output is obtained. "Inherent regulation" is usually expressed as a percentage of the rated load voltage and is obtained by observing the rise in voltage when the load changes from rated output (at rated voltage) to no load, at constant speed and without any external adjustment of the exciting circuit.

In the case of L.T. generators, as here described, all electrical parts must withstand the application of 220 volts A.C. between them and earth for a period of 1 min.

The test for insulation is made with a 500 volt megger immediately after the load run while the generator is hot; a lower value than 2 megohms is not accepted.

The limit for temperature rise above room temperatures is usually about 78° C. for low voltage generators. A telephone test for commutator ripple is made; such comparative tests often disclose defects such as incipient short circuits in the armature coils, defective soldering, etc.

Wherever possible a check test is made with the generator operating with its associated equipment (e.g. voltage control box, etc.).

The faults most frequently met with in generators, and the methods of testing and correcting, are—

Incorrect marking of the output plugs or socket, leading to cross connections when coupled to an external circuit: A test is made with the generator coupled to its load by means of the actual plugs provided.

Poor commutation leading to failure to excite, or, sparking under load. The commutator must be dead true both before and after test, the mica undercut (if so applicable), the brushes correctly bedded and free in their holders, and the whole armature perfectly balanced both statically and dynamically. It must be seen that the proper grade of brush is fitted and that the brush gear is in correct angular position and is truly rigid.

The driving end of the armature shaft is generally turned to a standard taper or otherwise adapted to carry a standard windmill, all mechanical dimensions at this point being carefully checked to ensure interchangeability.

Defective ball bearings: it sometimes happens that the race or its housing is of incorrect dimension and gives rise to unusual vibration and noise at full speed running.

End play is also checked and the radial tightness of the bearing proper should be such that there is no appreciable shake at working temperature conditions.

Armature whip is sometimes met with and is revealed by the armature rubbing against the pole pieces. This rubbing is often very difficult to detect, as it may only develop under full load and causes little more trouble than an increased rise of temperature. Whip is generally caused by a sprung shaft or by an armature imperfectly balanced statically or dynamically; these points must therefore be carefully watched.

Locking screws are a frequent source of trouble. As a dynamo is subjected to intense vibration from various sources it is important that all screws be adequately locked, and attention to this detail is imperative. The method of locking is not so important as the manner in which it has been done.

Loose field stampings occasionally give rise to serious trouble. The method of securing the stampings in position and preventing their rotation must be investigated, and the rigidity of the stampings tested.

Slack internal connecting leads are examined; if these are not securely anchored they sometimes come adrift and foul the revolving parts.

Metal dust in the bearing housings or in the armature tunnel. The stray magnetic field iron filings, etc., tend to resist ordinary methods of removal, and special precautions must be taken to see that the whole machine is free from metal dust and filings.

Armature bearings and wedges must be permanently secure. Shrinkable material which might cause ultimate failure must not be used in such positions.

The following procedure must be adopted before a generator is accepted—

See that the commutator is clean and free from any traces of grease or paint.

That the brush gear is free from carbon and copper dust.

Rotate the armature slowly by hand to confirm that no binding has developed during the cooling down after the load run.

Examine all end inspection covers for fit and weather proofing properties. (Where spares are stored in a box on the generator they are individually

packed in such a manner that they cannot be damaged by rubbing against one another.)

See that the shaft and other bright steel parts are treated for rust prevention by the application of vaseline, grease, or other suitable means.

Check the marking on the label: type identification, serial number, maker's name, year of manufacture, speed in revolutions per minute, output in volts and amps.

Aircraft generators are controlled automatically to give constant voltage irrespective of the load and speed (within certain limits); the average speed is generally about 5,500 r.p.m., but generators operate between approximately 4,000 r.p.m. and 7,500 r.p.m. Generators are, as already mentioned, usually driven by means of windmills coupled to the front end of the generator. The windmill should be properly mounted with its boss on the shaft and locked in position; it should be regarded as a small airscrew (see "Airscrews").

The generator should be mounted on a proper base or in a suitable cradle on the aircraft. It should be away from vapour and flame emitted by the engine, should be kept free of petrol, oil, water, or spray, and clear of anything by which it could be fouled or damaged. It should be kept clean.

The generator is mounted with its axis of rotation parallel to the horizontal datum line of the aircraft and in the unobstructed airscrew slipstream in such a manner that its whole body is exposed to the air flow. The close proximity of struts or other parts of the aircraft structure either forward of or abaft of the windmill must be avoided, as such obstructions may so distort the air flow past the generator that its performance is seriously impaired.

Connections to the generator are, as already mentioned, by means of a plug and socket fitting, the socket being permanently fixed to the generator with internal connections complete. This enables the generator to be quickly removed when not required.

The generator should be so mounted that the supply cables may be readily connected and disconnected; enough clearance must be allowed to permit the easy removal of the end fairing for the examination of the commutator and brush gear without disturbing the main body of the generator.

The generator cradle should be fitted so that the strap may easily be detached when it is required to remove the generator from the aircraft.

In order to avoid compass deviation due to the generator, the generator should be mounted as far as possible from the compass. In aircraft of metal construction the generator mounting, which should itself be of non-magnetic material, should be kept well away from any member of the aircraft which passes near the compass.

Air-driven generators can usually be run up to speed on the aircraft for testing purposes (though not usually to full load) by running the engine on the ground. A satisfactory voltage regulator test, as later described, will also show that the generator is in running order. If a doubt exists as regards its ability to give full output, arrangements should be made for a test by a portable engine with a flexible drive, or the apparatus should be removed for bench test. The following matters should receive attention from time to time—

The bearings should be free. These are usually packed with grease and need no oil.

Commutators should be kept clean and, when necessary, polished with fine grade glass paper.

The grooves between the commutator segments should be free from copper dust and dirt. A fine pointed scraper may be used to clean out the grooves.

Brushes should bed evenly on the commutator and work freely in their holes, the spring transmitting an even pressure of the brush on the commutator.

The bolts securing the brush carrier to the frame should be tight.

Field Shunt

A suitable resistance connected in parallel with the field windings of such a generator as has been described improves the performance of both generator and the control box by—

(*a*) Reducing sparking at the control box.

(*b*) Improving commutation.

(*c*) Increasing generator output.

The shunt consists of a resistance unit totally enclosed in a sheet metal case. The resistance element consists of a flat mica former, wound with 33 S.W.G. bare Eureka wire to a total resistance of 25 ohms. The ends of the resistance wire are brought out to terminal tags on to which are soldered two 8-in. leads of uniflex 4 cable. The terminal tags are riveted in position on the mica former.

The former is mounted between sheets of micanite suitably grooved to accommodate the flexible leads and terminal tags, the grooves being filled with shellac during assembly.

The aluminium case is made in two portions, the front being bent or folded round to enclose the resistance element and the back cover; the whole is then riveted together by means of four brass eyelets, which also form holes for four fixing screws. Washers are riveted in position under the eyelets on the back of the unit to ensure that the shunt stands clear of its mounting when screwed in position. Free circulation of air round the unit is thus permitted.

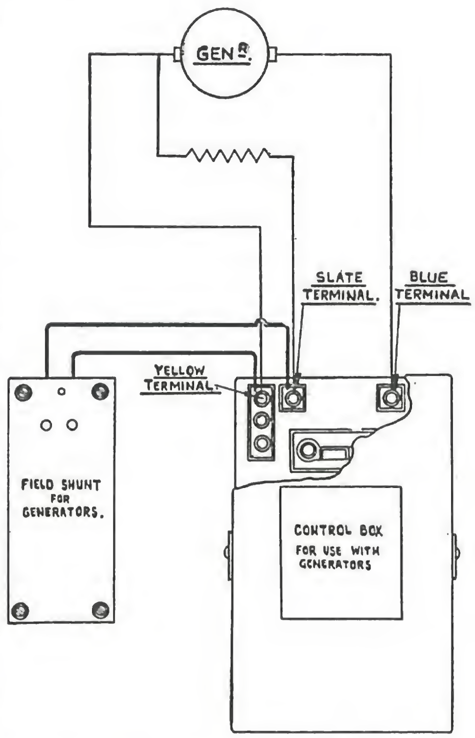


FIG. 74. GENERATOR, VOLTAGE CONTROL BOX AND FIELD SHUNT; METHOD OF CONNECTION

The shunt should be mounted as close to the control box as possible, and in a vertical position, to permit free circulation of air round the shunt. The flexible leads should be connected to the yellow and slate-coloured terminals of the voltage control box, thus putting the resistance in parallel with the generator field as shown in Fig. 74.

When installing the shunt care should be taken to cleat the leads securely and as close to the shunt as possible.

Voltage Control Box

(For control of the air-driven generator described.)

The generator, as already stated, is controlled by means of a voltage

control box. This system of control maintains the voltage at a constant figure. It is used in conjunction with all shunt-wound generators which are not self-regulating. (The apparatus may vary, for example, a late type (vibrating reed type) of control box also incorporates within itself a generator field shunt, instead of this item being separately installed, as is the case in connection with the box here dealt with.)

The apparatus, the arrangement of which is shown in Fig. 74, incorporates a cut-out which automatically disconnects the battery from the charging circuit if the battery begins to charge back into the generator. From Fig. 75 it will be seen that a solenoid coil L_1 is connected across the generator armature terminals. In series with this winding is connected a fixed ballast resistance R_2. As soon as the generator terminal voltage rises beyond a predetermined value the solenoid operates and breaks the contacts S_1 by the attraction of the armature A_1. This armature is connected to the lower right-hand terminal via the iron core of the solenoid; this connection is therefore shown by a dotted line in the diagram. The breaking of the contacts S_1 connects the regulating resistance R_1 and the "bucking" winding L_2 in series between the generator field terminal and the negative armature terminal. This weakens the generator field, and the terminal voltage immediately falls. As soon as the voltage falls below normal, the armature A_1 is pulled away from the solenoid by a control spring. The resistance R_1 and the bucking winding L_2 are then cut out from the circuit.

The battery cut-out consists of a solenoid coil L_4, which is connected between the positive battery connection and the positive generator connection. When the generator is supplying current the coil L_1 energizes the iron core of the main solenoid, and the armature A_2 is thereby magnetized to a definite polarity and attracts the main solenoid, thus closing the bridge contacts S_2.

The current through the solenoid coil L_4 flows in such a direction as to assist the action of the main solenoid by attracting the armature A_2 about its pivot. It should be noted that the battery is connected across the terminals B_1, and B_2 as shown. When the battery commences to discharge into the generator the current through L_4 is reversed and the solenoid acts in opposition to the main solenoid. The contacts S_2 now break and the generator armature circuit is disconnected from the control box.

The component parts are mounted on a hollow rectangular aluminium base, which is closed by an aluminium back plate lined with mica to eliminate fire risk. The front aluminium cover is held in position by two brass catches. Inside the cover is a diagram of connections, together with instructions for adjustment.

The instrument should preferably be mounted in a protected position, in order to secure maximum cooling effect, and in such a way that adjusting screws can be readily manipulated (this remark also applies to any separate battery cut-out which may be in any special installation). When handling the control box with the cover removed, care should be taken not to bend or damage any of the springs or moving parts, and to prevent any foreign matter, especially metal such as wood screws, from becoming lodged in the apparatus during installation.

The instrument is supplied by the makers correctly adjusted and ready for use, and except when necessitated by imperfect operation the various adjustments should not be interfered with. (The voltage setting should not be changed provided the voltage is between 13·5 and 15. Under these conditions with a 12-volt 25 amp.-hour accumulator in good condition, all navigation lights can be kept on continuously during all night services.)

The cover should always be kept on to protect the instrument from accidental damage.

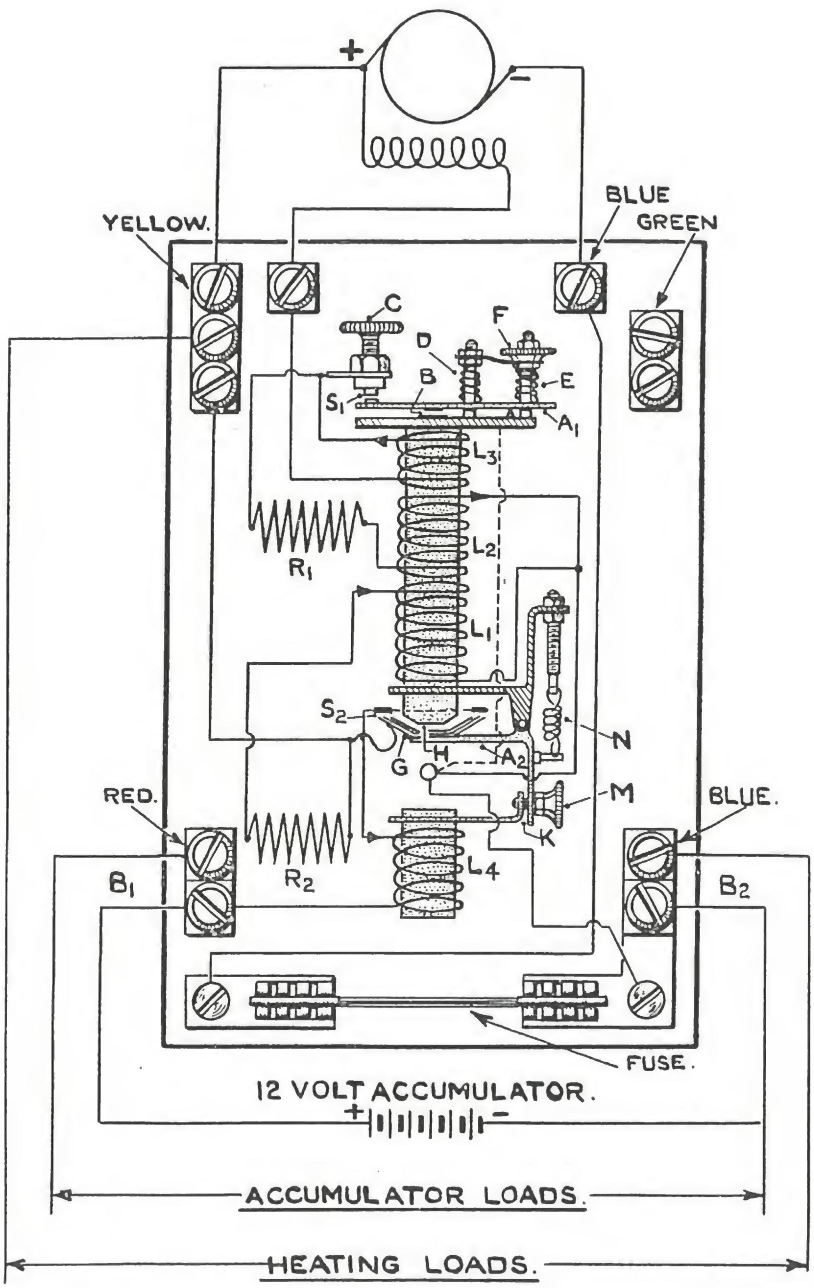


FIG. 75. VOLTAGE CONTROL BOX—DIAGRAM OF CONNECTIONS

The regulator is set to give 13·5 volts when cold; during flight this may rise to 15 volts, owing to temperature effects, but the average value should be about 14 volts.

The battery cut-out is set to close at about 12·5 volts and cuts out with a discharge current of about 4 amps. The magnetic circuit of the battery cut-out is arranged to react on the main solenoid circuit in such a manner that a charging current into the battery has the effect of slightly reducing the generator voltage, the reduction in voltage being dependent on the charging current. The voltage change is, however, small, being about ·5 volts, with a charging current of 15 amp.

The foregoing effect is an advantage because it tends to limit excessive charging current into the battery, which is almost discharged. As the battery voltage rises the charging current is reduced, and the generator voltage rises accordingly until the battery is fully charged and is floating with full voltage from the generator.

The vibrating contacts of the regulator should be clean and the carrying arm free in its bearings.

The brush blades of the cut-out should be clean and making good contact when the cut-out is in charging position.

Tests are made with a portable voltage tester. This instrument contains a voltmeter with flexible leads and plugs for connecting it to the regulator; the instrument, which incorporates a telephone jack, provides a simple means for testing whether the controller is maintaining the correct generator voltage, and the telephones give an aural indication that the regulator is in operation. Instructions for use of the testing instrument are to be found inside the cover.

With full load on the generator some sparking will be observed at the regulator contacts. This is quite normal and has no adverse effect.

If any voltage adjustment is required during flight, the tension of the front control spring on the upper armature should be adjusted by the milled screw *F*. No other adjustment should be attempted when in the air; other adjustments should be made during overhaul on the ground.

At the end of every 100 flying hours the control box should be carefully overhauled. The regulator and battery cut-out contacts should be carefully cleaned and readjusted, the method being as follows—

(*a*) Disconnect the battery leads.

(*b*) Remove the armature A_1 and the screw *C*.

(*c*) Clean and burnish the contacts S_1 and replace armature and set screw. See that the contact faces are parallel after cleaning.

(*d*) Set the air gap *B*, the armature and solenoid core to the thickness of a ·015 in. feeler by the adjusting screw *C* and tighten up the lock nut. When setting the air gaps see that the contacts are closed and the armature properly seated on the fulcrum.

(*e*) Tighten up the tension spring by giving two complete turns of the securing nut and tightening up the lock nut.

(*f*) With the generator running at 4,000–5,000 r.p.m. and the voltmeter connected across the yellow and blue terminals, set the voltage to 13.5 by adjusting the tension of the spring *E* by means of the screw *F*, and after adjustment secure with the lock nut.

To adjust the battery cut-out—

(*a*) Disconnect from the accumulator and remove the armature A_2.

(*b*) Clean and burnish the contacts S_2 and replace the armature.

(*c*) Adjust the bridge contacts *G* to obtain even contact; when contact is just made the air gaps should be the thickness of a ·015 in. feeler.

(*d*) Set the stop screw *M* to give maximum opening of the air gap *H* to thickness of feeler.

(*e*) With the generator running, adjust the tension of the spring *N* until the contacts close at approximately 12·5 volts.

(*f*) Connect the accumulator and finally adjust the spring N until the contacts open with a battery discharge current of 4–5 amp.

After adjustments tighten up all lock nuts.

Note. On some control boxes a single pole fuse is placed in common negative main circuit; in others there is no fuse, all fusing being done externally.

Engine-driven Generator

The generator here described is the alternative of the air-driven type and has an output of 500 watts at 14 volts at about 5,000 r.p.m. at normal cruising engine speed. It is directly driven from the engine and in connection with the accumulator is self-regulating.

A suitable accumulator cut-out and a manually operated position switch, together with a resistance enables the charging current to be

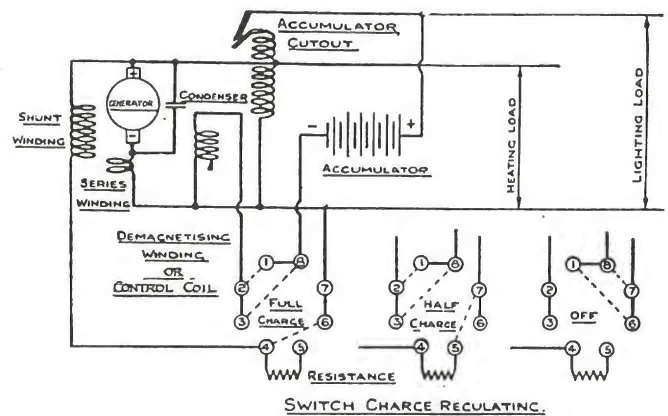


FIG. 76. ENGINE-DRIVEN GENERATOR—DIAGRAM OF CONNECTIONS

reduced when the accumulator becomes fully charged, or the generator to be switched off completely.

The control of the generator is effected by special field windings in connection with the accumulator. The shunt-field winding is connected across the lines, and the armature current is passed through a series winding to give load compensation as in an ordinary compound wound generator. The control winding is of low resistance and wound in the reverse direction, and carries the accumulator current only.

When the system is in operation the voltage of the generator rises until the cut-out contacts close and charging current flows to the accumulator. This charging current, flowing through the control winding, exerts a demagnetizing force on the field system and prevents any further material rise of voltage. Thus, as the speed of the generator increases the charging current automatically rises just sufficiently to give the necessary reduction in field strength and maintain the line voltage approximately equal to that of the accumulator. As all external load currents are supplied directly from the generator, and do not pass through the control winding, the charging current and voltage control are independent of the load conditions. When the generator falls below the minimum speed at which it can supply the load connected, the cut-out contacts open and lighting loads are maintained from the accumulator through the control winding, which is of low resistance.

The line voltage under normal conditions is always slightly in excess

of the accumulator voltage and as the latter rises as the accumulator approaches the fully charged state, a switch is provided to reduce the charging rate, thereby restoring normal voltage and avoiding excessive overcharging. The switch has three positions: "off," "half charge." and

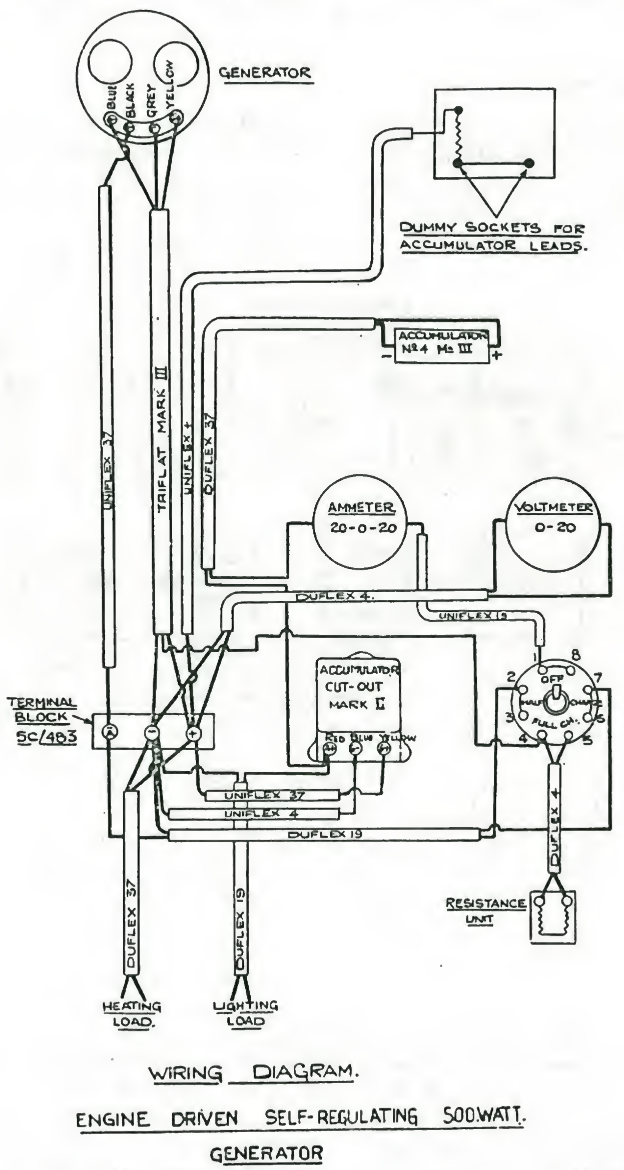


FIG. 77. ENGINE-DRIVEN GENERATOR—WIRING DIAGRAM

"full charge." The effect of moving the switch to the "half-charge" position is to insert the resistance unit into the shunt-field circuit of the generator. When the switch is in the "off" position, the accumulator is connected directly to the lighting mains, and the generator shunt and control field circuits are broken, thus preventing excitation of the generator.

Dummy accumulator sockets are wired to the system in such a way

as to prevent excitation of the generator if the aircraft is flown without an accumulator. This is effected by connecting the negative accumulator lead to the generator positive lead, thereby converting the generator control winding into a powerful shunt winding of demagnetizing polarity when the control switch is in the charge positions. Connection to the positive accumulator lead is immaterial, but the dummy terminals are connected together so that in stowing the leads polarity need not be observed.

A small resistance (about 1 ohm) is incorporated in the dummy terminal block. The object of this is to limit the short-circuit current which would flow in this circuit due to the residual generator voltage where the control switch is in the "off" position.

With the control switch in the "off" position the generator is out of action, and the lighting loads and essential services are supplied from the accumulator. At the beginning of a flight, the switch should be placed in the "full charge" position, when the generator will supply all loads connected and in addition charge the accumulator at about 3 amps.

After a time, depending upon the initial state of the accumulator, the fully charged state will be approached. This will be shown on the voltmeter by a rise in voltage which, if allowed to continue, may possibly reach 17 volts. The switch should be moved to the "half-charge" position when the voltage exceeds $14\frac{1}{2}$ volts. This reduces the voltage to about 14 volts and the charging rate to a small value (0 to 1 amp.). Where a fully charged accumulator is placed in the aircraft this effect will usually occur in the first few minutes. Throughout the remainder of the flight no further attention should be necessary.

It is imperative that the engine should not be run unless the accumulator leads are properly connected to an accumulator or stowed in the dummy sockets provided. A faulty connection in this circuit will lead to excessive voltage and damage to the generator and any services connected if the control switch is inadvertently placed in the "charge" position.

21. ACCUMULATORS

Lead-acid Accumulators

(No account is here taken of ordinary bench recharging, as it is considered beyond the normal function of the ground engineer. Charging from the generator has already been dealt with.)

Accumulator cells (see Fig. 78) usually consist of several positive and negative plates (generally made of lead and paste filled), arranged alternately throughout the cell.

Each positive plate has a negative plate on each side of it. The plates are prevented from touching by separators, usually celluloid, ebonite, or wood partitions arranged so as to permit free circulation of the electrolyte between the plates. If this is impeded by any means, the electrolyte will not be of uniform density throughout the cell, which will result in buckling of the plates and the shedding of active material.

The separators always have vertical grooves further to allow of the equalization of the electrolyte density. A certain amount of space is left between the bottom of the plates and the separators to allow any active material which may be shed in the form of sediment to fall to the bottom of the container clear of the plates, which it would otherwise short circuit. The electrolyte in all ordinary cells consists of sulphuric acid of a specific gravity of 1·84 diluted with distilled water to a specific gravity of 1·27. The specific gravity of the electrolyte may be tested by a hydrometer, several special kinds of which are obtainable for this purpose.

For aircraft purposes the weight and size of accumulators are kept at a minimum with some sacrifice in life.

The normal useful life of such accumulators in temperate climates may be reckoned as about 70 complete cycles of charge and discharge at the 10-hour rate, or 700 working hours at 10 hours a day. If the working hours are 5 per day then the useful life would be approximately 2,000 hours; it may be thus said that the useful life may be taken as from three to five months.

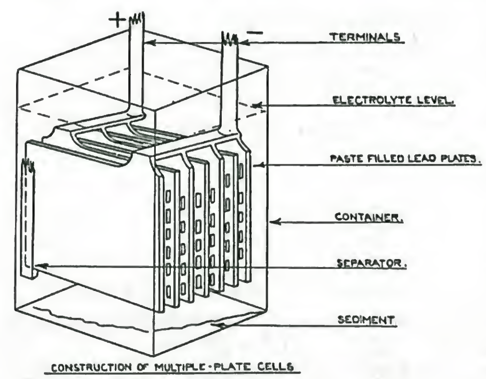


FIG. 78. ACCUMULATOR—CONSTRUCTION OF MULTIPLE PLATE CELLS

Under tropical conditions the life may be very considerably shortened, even to one or two months.

By useful life is meant the number of cycles of charge and discharge which reduces the original cell capacity to 40 per cent. In tropical climates frequent inspection is necessary and evaporation of the electrolyte, if rapid, should be compensated for by "topping up" daily with distilled water.

The voltage of an accumulator in a fully charged condition is practically a fixed quantity. On open circuit the potential difference between the positive and negative plates is usually about 2·2 volts. The terminal voltage falls as the cell discharges, the rate at which the voltage falls being dependent on the rate of discharge. In Fig. 79 a curve is given showing the fall of the voltage on discharge at the 10-hour rate.

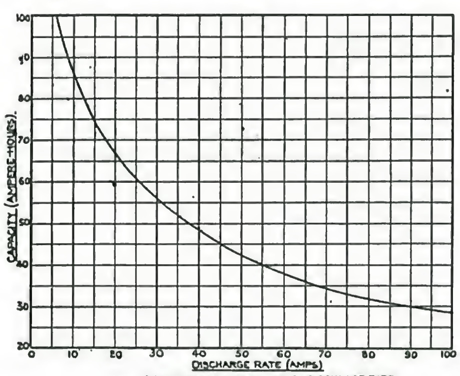


FIG. 79. VARIATION OF CAPACITY WITH DISCHARGE RATE

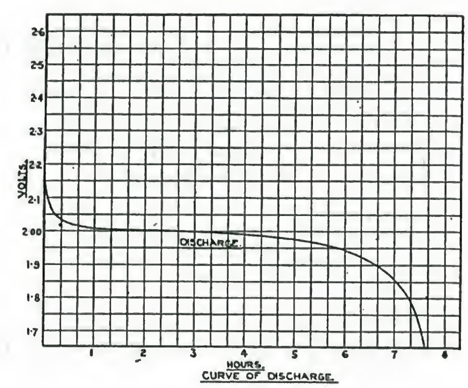


FIG. 80. CURVE OF DISCHARGE

The capacity of an accumulator is its output expressed in ampere-hours. The capacity thus represents the product of the current (in amperes) and the time (hours) for which that current can be taken from the cell when fully charged until the terminal voltage falls to 1·8 on load. The normal rated capacity of a cell is usually based on the 10-hour rate of discharge, i.e. the current which will discharge the cell to 1·8 volts in 10 hours; when this discharge rate is exceeded the capacity is reduced. It should be realized that a 40-amp.-hour accumulator will not give 20 amp. for 2 hours

nor 10 amp. for 4 hours; it is rated to give 4 amp. for 10 hours, and if the discharge current exceeds 4 amp., the ampere-hour capacity will be reduced. For example, in Fig. 80 if a 2-volt 90 amp. accumulator is considered—

At the 10 hour rate its capacity is 90 amp.-hours
,, 5 hour ,, ,, 75 ,,
,, 1 hour ,, ,, 45 ,,

This means that the accumulator will give 9 amp. for 10 hours, 15 amp. for 5 hours, or 45 amp. for 1 hour. In each instance the current rating of the accumulator for the period specified is that which would bring the terminal voltage of the cell down to 1·8 on closed circuit starting from the fully charged condition. The capacity of any cell is not, therefore, a constant quantity, but depends on the amount of active material in the plates.

Faults

The following faults may be attributed to improper treatment of free acid accumulators—

Sulphation, hydration, buckling of plates, disintegration of plates, internal short circuit, damaged containers.

Sulphation is the most common fault, generally caused by neglect by (*a*) discharging below 1·8 volts per cell, (*b*) allowing to stand partly or wholly discharged, (*c*) continuous undercharging, (*d*) using too strong an electrolyte.

The treatment for sulphation consists of (1) emptying and washing out with weak electrolyte; (2) refilling with weak electrolyte (specific gravity about 1·15); (3) sending for charge at one-quarter the normal rate with instructions to allow to gas steadily, thereby dislodging insoluble sulphate which falls as sediment. (It may be necessary to continue this charge for 100 or more hours.) (4) emptying out, washing out sediment with weak electrolyte and filling up with normal fresh electrolyte; (5) charging the cell at the normal charging rate for a short period.

Should the above treatment not be successful in removing the insoluble sulphate, the cell may be carefully dismantled and the plates taken out, scrubbed, and scraped carefully to remove hard sulphate. Great care is essential in order not to disturb the paste or active material of the plates in any way. Re-assemble the cell and place on slow charge until restored to normal condition. However careful the treatment, it should be noted, of course, that the life and capacity of the cell will have been impaired by sulphation.

Hydration is caused by allowing water to remain in contact with the active material of the plates for a long time. New accumulators should not be rinsed out with distilled water before the first charge. Hydration interferes with the chemical changes which take place during charge and discharge and impairs capacity. Treatment consists of prolonged charging on the lines of (3).

Buckling of Plates is generally due to excessive rates of charge and discharge causing uneven chemical action in the active material of the plates, which are thereby buckled by the stress. To remedy, the plates should be taken out and pressed gently between pieces of board, due care being given to the brittleness of the plates and the likelihood of loosening active material and causing shedding.

Disintegration of Plates may be caused by general neglect, prolonged overcharging and continuous charging at current strengths much less

than those indicated on the label; the result is peroxidation. There is no remedy. The consequent sediment should be removed to prevent it short-circuiting the plates, the cell being carefully shaken and emptied, filled with fresh electrolyte and sent for charge at one-half the normal rate.

Internal Short Circuits will be indicated to the persons responsible for charging. They may be caused by neglect or by lead "growths" (which will expand when warm) due possibly to prolonged undercharging below the normal rate. The plates should be taken out and cleaned of any excrescences.

Damaged Containers may result from stopped-up vent holes. When sending for charging, those responsible should be informed of any sealed vents. Celluloid cased accumulators should be kept out of the discolouring and strength reducing heat of the sun. High temperature from any source may cause discoloration and warping and cracking of containers, sulphation, hydration and buckling of plates, inability to hold charge, and expansion of positive plates during charge to such an extent as will result in entire failure.

Inspection

Terminals should be tight and a light coat of vaseline should be applied to prevent detrimental effects due to acid. Vent plugs should be tight. The electrolyte should be kept to the proper level in accordance with instructions or level-mark. Cables to the accumulator must be correctly attached as regards polarity—red cable to positive and blue to negative. The cable terminals should be fitted in a dummy plug when not in use. Accumulators should not be left in an uncharged or partially charged condition, as either will lead to sulphation. When not required for use they should be given a freshening charge at least once a month.

Test

The condition of an accumulator can be ascertained by a discharge test at the 10-hour rate (discharging at a current equal to one-tenth the nominal capacity) and the voltage recorded against time. A fully charged accumulator will give about 2·1 volts at the start of this test and not less than 1·8 volts per cell after 10 hours. If the voltage falls to 1·8 in less than 6 hours it will indicate that the accumulator is not in a very serviceable condition. Accumulators must be wholly of the non-flame or non-flame-top type, and preferably non-spillable (in acrobatic aircraft they are compulsorily so). They must be kept as far as possible from fuel tanks and engine.

The accumulator should always be protected from the weather, housed clear of all the usual places of passenger occupation and of all hand and walk ways, etc., but of course should be easily accessible at all times for inspection, test of electrolyte, voltage, etc., recharging and general maintenance. Care should be taken that it is securely fastened and locked in place, taking into account vibration. All live parts of the accumulator must be enclosed or protected. The box or compartment into which the accumulator goes must be adequately vented, must insulate the accumulator's celluloid sides (if applicable) from the air, and it must be entirely leak-proof. Spilled acid is highly destructive to most materials; it may find its way to a stressed member of the aircraft and by its rapid attack cause structural failure. Any signs, therefore, of free acid must be at once investigated.

Alkaline Accumulators

The nickel-iron accumulator is now very often used in place of the lead-acid type and owing to its long life and durability is especially suited for use in aircraft where the working conditions are extremely vigorous.

The positive and negative terminal places are perforated nickel-plated steel containers which are filled with the active material. The plates are welded or bolted together for similar polarities and separated by strips of hard rubber. Each cell container is a thin welded nickel-plated steel box entirely closed except for a special non-spillable gas release-valve which effectively prevents spilling of the electrolyte while allowing the gases generated during charging to escape. An important characteristic of this cell is that it may be charged or discharged at a very high rate and left in a discharged condition without injuring it in any way.

Accumulators must be capable of supplying navigation lamps, identification and landing lights, etc., and all services where continuity and existence of current is essential for at least 30 min. after the generator has stopped.

22. LOW TENSION INSULATED CABLES

There are many different classes, all L.T., of cables used in the electrical general service equipment of aircraft. Each class has a different number of cores from that of any other class. The cores consist of stranded tinned copper insulated by pure vulcanized rubber sheaths and wrapped in coloured cotton. In some cases the rubber sheathing itself is coloured. The number of cores comprising the cable of each class is indicated by the prefix of the class name (see Fig. 81).

Thus the class of cable containing a single core has a prefix "uni" that containing two cores "du," that containing three cores "tri," and so on. In nearly every class there are four types of cable; each type differs from the others in its class by the nature of the sheath in which the cores are enclosed. The nature of the covering sheath is indicated by the suffix of the class name; thus: the suffix "flex" (flexible cables for general use in protected positions) indicates that the core or cores are covered by a sheath of braided cotton; the suffix "proof" (waterproof cables) indicates that the cores are covered with a braided waterproof material; the suffix "sheath" indicates that the cores are enclosed by a tough rubber sheath for use in unprotected positions where they are liable to be rubbed against or otherwise roughly treated. The numeral following the name of the cable denotes the permissible current carrying capacity of that particular cable. Thus "uniflex 4" will carry 4 amp. "duflex 19" will carry 19 amp., and so on.

At standard current rating and for small cables up to and including 19 amp., all the sizes allow a drop of ·1 volt per yard run, 37 amp. cables allow a drop of ·1 volt per yard and a half run, 64 amp. cables allow a drop of ·1 volt per two and a half yards run. In the fifty power cables carrying 175 amp. the voltage drop is ·1 volt per yard run.

The fourth type of cable is of the sheath type closely braided with metal wire and is for use in aircraft in which directional wireless is installed.

In addition to these cables is a cable known as "Tripod" which is similar to "tri-sheath," except that it has cores of different colours. Tripod is a metal wire braided cable.

Special cables, "Triflat," are used for connecting up generators. The cables consist of three insulated cores contained in a shallow sheath of tough rubber. Triflat is also supplied braided with metal wire.

The cable known as fifty power is for connecting up electric starter motors. The core is a large diameter-stranded cable insulated by pure

vulcanized cambric tape and by one plain and two oil-resisting layers of varnished cambric tape. It is closely braided with paint impregnated cotton.

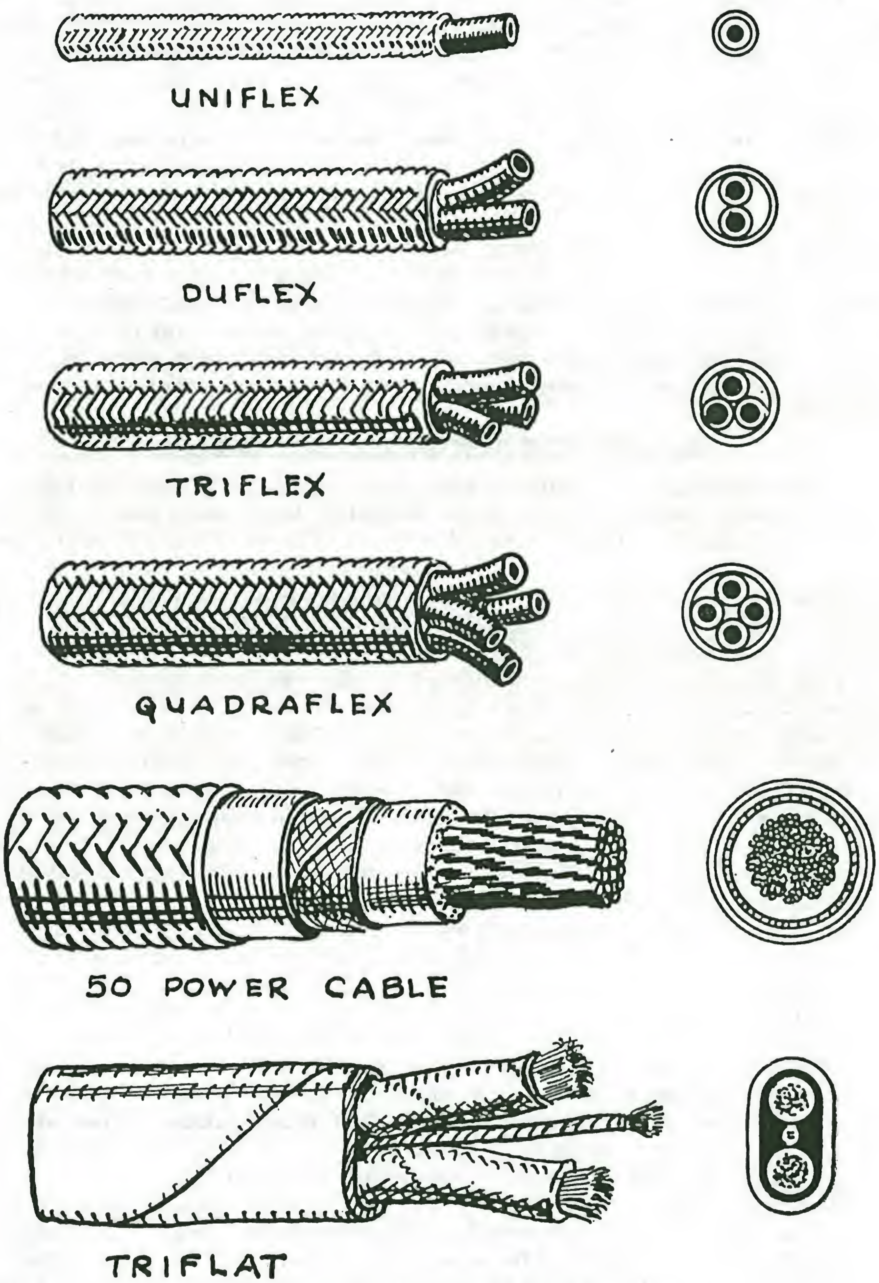


Fig. 81. Types of Cable

For instrument lighting a cable known as "instruflex" is used. This consists of two plain stranded copper cores insulated and wrapped respectively with red and black cotton. The cores are not enclosed in a sheath but are twisted together.

Below is given a list of stranded low tension cables—

Type	*Number.*
Uniflex	4, 7, 19, 37, 64.
Uniproof	4, 7, 19, 37, 64.
Unisheath	4, 7, 19, 37, 64.
Unisheath braided	4, 7, 19, 37, 64.
Duflex	4, 7, 19, 37, 64.
Duproof	4, 7, 19, 37, 64.
Dusheath	4, 7, 19, 37, 64.
Dusheath braided	4, 7, 19, 37, 64.
Triflex	4, 7, 19.
Triproof	4, 7, 19.
Trisheath	4, 7, 19.
Trisheath braided	4, 7, 19.
Tripod	
Tripod braided	
Triflat	
Triflat braided	
Quadraflex	4, 7, 19.
Quadraproof	4, 7, 19.
Quadrasheath	4, 7, 19.
Quadrasheath braided	4, 7, 19.
Twensevenflex	2.
Fifty power	
Instruflex	
Quintoflex	4, 7.
Quintoproof	4, 7.
Quintosheath	4, 7.
Quintosheath braided	4, 7.
Sextoflex	4.
Septoflex	4.
Nonoflex	4.

Where screened metal-braided cables are required in an exposed position, and where there is a danger of damage or corrosion to the braid, the following are used—

Dumet	4 T.R.S.
Tumet	4 T.R.S.
Quadramet	4 T.R.S.
Quintomet	4 T.R.S.

The letters T.R.S. indicate a tough rubber sheathing over all.

Lately, cellulose varnished cables have come into use; these follow upon the lines of the above, being named unicel, ducel, tricel, and numbered 4, 7, 19, etc., as the case may be.

It should be borne in mind that all cables here dealt with are designed with special regard to lightness in weight and they are not suitable for hauling through small holes or other confined spaces. Every precaution should be taken that they are not subjected to undue stress.

Electrical systems which the cables are called upon to serve may be grouped under these headings: ignition, wireless, intercommunication, and general.

For the purpose of recognition the cables serving the various systems have coloured coverings or are coloured distinctly during their installation and are secured by appropriately coloured cleats. The colour scheme is as follows—

Ignition	blue
Wireless	red
Intercommunication	green
General	yellow

The colours are also borne by the ends and the respective cleats and elsewhere to allow the run of the cable to be traced. Where cleats are inadmissible the cables are painted with bands of their distinguishing colours.

The cores of the various types of cable are wrapped in coloured cotton lapping as already mentioned. The colouring denotes the polarity or function of the core.

The general colour scheme is as follows. Single colours are used as far as possible, and extensions of these colours are employed for multiple cables. Those in most common use are—

Single core, natural colour.
Two cores, red and blue.
Three cores, red, blue, and green.
Four cores, red, blue, green, and yellow.

The key colours for main circuits are—

Red . . .	accumulator positive circuits.
Blue . . .	negative, all circuits.
Green . . .	neutral.
Yellow . . .	generator positive circuits.
White . . .	used as special cases demand.
Grey . . .	generator field conductor in triflat cables.

Cable Installation

Care must be taken to prevent cables coming into contact with moving parts such as control wires, or levers, or sharp edges of fittings or ducts or other equipment.

Where practicable it is advisable that the lengths of cable should exceed the minimum necessary to meet installation requirements by approximately 2 in., so that if end breakage occurs the connection can be re-made without using new cable. The excess lengths at the ends of the cable should be properly secured.

No splicings, twistings, solderings, or any other joints are permitted in a length of cable.

There must be no risk of oil, petrol, or dope coming into contact with the cables, which must be installed in such a way as to not be liable to accidental damage by persons getting into or out of, or moving about, or in the course of flying in, or maintaining, the aircraft.

Wherever necessary, cables must be protected from the effects of weather, sea water, dampness, or other atmospheric or similar deleterious conditions.

The progressive effects of continuous vibration must be carefully guarded against. The cables should only be taken through bulkheads, fairings, fabric, and the like by means of adequately bushed holes.

The installation should provide for adequate support to the cables throughout their length, unnecessary hangings, loops, or slacknesses, or undue stressing being strictly avoided.

The fixings for cables, ducts, cleats, and the like, or any other item of the electrical equipment must not involve the drilling of holes or the making of passage ways which are liable to weaken any part of the aircraft structure.

Cable ends must be properly finished off as described hereafter and whilst being securely fixed in their terminals or other appropriate fittings, must not be under any mechanical stress; due allowance should be made for expansion and contraction, and for torsion of the structure.

The various items of equipment should as far as possible be grouped

together on one side of the aircraft, to simplify wiring and connecting up and to avoid wiring being taken across the fuselage or hull.

Cable runs for general lighting and heating circuits must not be run in common ducts with wireless, ignition, or other circuits and must in fact be separated as far as available space permits.

Serious interference with W/T and direction-finding apparatus may result from the close proximity of other electrical systems. The cables must be readily accessible throughout their length in order to facilitate inspection or replacement.

Cables may be carried in systoflex or in open metal ducts or tubular fairings or conduits. Open ducts designed to carry a number of cables should be provided with front covers or narrow clips which can be sprung on the edges of the ducts. Such ducts are sometimes lined with sponge rubber, which lightly pressing on the cables when the trough is closed, prevents movement.

It is advisable to stencil, or mark with a coloured band in accordance with the key as already given, all closed troughs and ducts.

Tubular fairings and circuits must have clean, smooth bores. Ducts and fairings should be bell-mouthed bushed to prevent abrasion cutting through the cable insulation, with consequent short circuiting. Metallic cable conveyances as mentioned above should of course be "brought in" the bonding system of the aircraft where applicable.

To facilitate erection and dismantling the aircraft, suitable provision should be made for severing and re-uniting the electrical circuits at the junction of detachable components. A terminal block is suitable for this purpose, provided it is easy of access.

On aircraft with folding wings the terminal block should be placed near the hinge joint, and the cable arranged in such a way as to obviate any detachment, fraying, or detrimental effect.

Adequate precautions are to be taken to prevent the twisting of cables whilst being drawn through tubes or fittings; such twisting leads to the formation of kinks and possible fracture.

If it is ever necessary to leave cable ends loose they should not be left bare. Each end should be protected by wrapping with insulating tape. Bare ends should never be twisted together. Along spars, struts, longerons or decking, where a clear run may be obtained without the cable fouling metal fittings, the cable or cables may be attached with aluminium cleats. These may be formed by lengths of aluminium strip bent to shape as shown in Fig. 82*a* and secured at each end with a small woodscrew. The cables where they pass beneath the cleat should be armoured against abrasion by being covered with a case of rubber or systoflex (insulation-impregnated braided cotton) strip or tube. Where more than one cable is secured by a single cleat the set is wrapped together in a protecting strip or passed through a common length of systoflex tubing. Where the cables pass transversely across a spar, strut, or longeron, the protective covering is carried $\frac{1}{4}$ in. beyond each edge.

Through decking and solid ribs where the cable is taken through a structural component of the aircraft it is protected by a bush of petrol-resisting rubber piping of sufficient length to project for $\frac{1}{2}$ in. on each side. The bush is a comfortable fit for the cable before assembly and a snug fit in its hole.

Should any difficulty be found in drawing the cable through its bush, French chalk is the only lubricant permissible.

It is impossible, as a rule, to carry a cable along the face of the main spars inside planes owing to its fouling bracings and other metal fittings;

it is therefore often suspended to the rear of a spar in straps of the type in Fig. 82*b*. The free ends of the strap are secured to the various ribs by small screws or fastenings.

Through fabric the cable is passed through a leather washer sewn to a patch: this patch is doped to the fabric so that the washer is located between the fabric and the patch.

Covered components should show the presence of internal electrical fittings or attachments by bearing upon inspection doors or patches an inscription such as "Electrical connections here," etc.

Between fin and tail plane the cable is run in the manner shown in Fig. 82*a* and is taken up the rear vertical spar, often terminating in a plug socket unit clipped to the side of the spar on the outside of the fabric; from the plug a length of cable is run inside the fabric of the rudder to emerge again close to the tail navigation lamp mounting. A short loop is left between the plug and where the cable enters the rudder of sufficient length to permit free movement of the rudder. The loop and the portion of the cable close to the navigation tail lamp fitting which is outside the rudder is enclosed in a length of rubber or systoflex tubing, the ends of which are served with prepared twine to prevent the entry of water.

Where cables are taken along tubular structural members of metal aircraft they are secured by being bound with six turns of 22 S.W.G. tinned-copper wire; the individual turns of the binding are soldered together in two places across a diameter of the tube so that the heat of the soldering does not damage the insulation of the cables; the cables are protected against abrasion as already described in the case of installation, "along spars, struts," etc.

Where cables cross members of all-metal aircraft they are secured by cleats of the type shown in Fig. 82*a*. These cleats are wired in place and the cables protected against abrasion in the usual way. Cleats must not be secured to hollow or built-up wooden spars or other components likely to be split or damaged by their being secured with wooden screws. If possible the cleats should be fitted only at places stiffened by packing blocks, and the cables should be supported at intermediate points by doped fabric or other suitable slings.

Live wires in the vicinity of fuel tanks and pipes must be suitably encased.

All cable ends at terminals should be distinctly marked: this is often done by coloured sleeving and sleeves bearing the name of polarity and service.

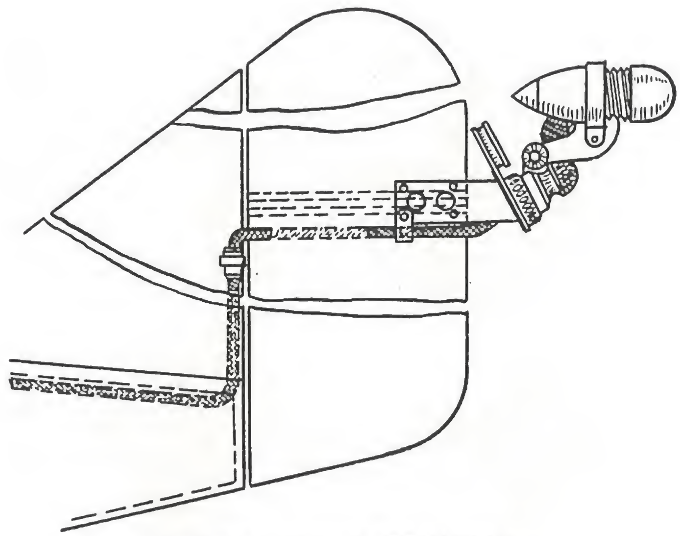
When making-off ends of cables, no frayed ends should be left out, all strands being in good contact. The following is a method of preparation—

Cut the outer covering back $1\frac{3}{4}$ in., fit the identification sleeve over the outer covering, serve with sailmakers twine or thread, cut the inner covering back according to the size of terminal screw, make and form the bare copper end into an eyelet, then bind the shank end with insulating covering tape or thread of the correct colour. Care should be taken that no strands are severed during insulation stripping.

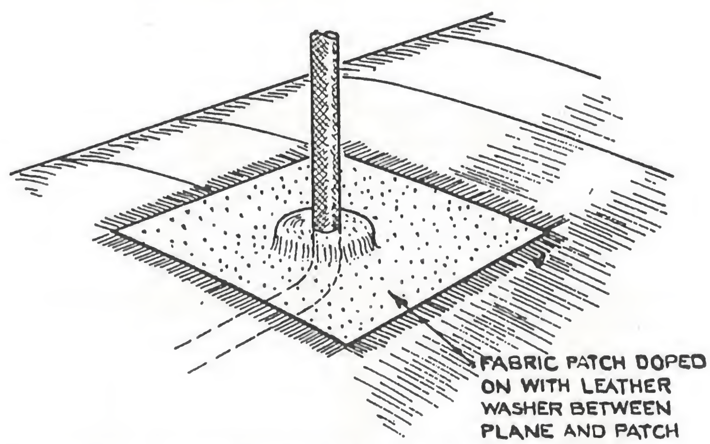
Except in special cases soldering together of the individual strands of a flexible cable is not permissible, as strands may be easily broken and the general flexibility of the cable at the soldered joint is lost.

Soldered cable ends may be required where—

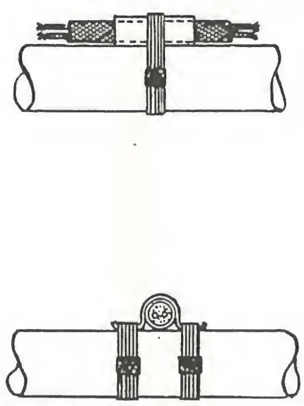
1. Slotted terminals are employed with an inside screw pressing on the cable ends; in such cases a soldered shank should be formed on the end of the cable.
2. Small eyelets with lugs are used.
3. Lugs with thimbles are used, as on some plugs and sockets.

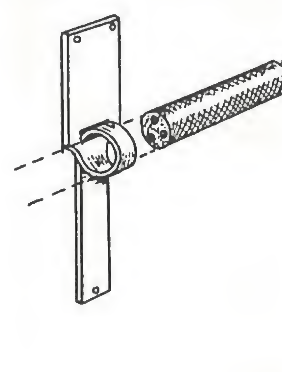


METHOD OF RUDDER WIRING.



METHOD OF BRINGING CABLES THROUGH FABRIC.

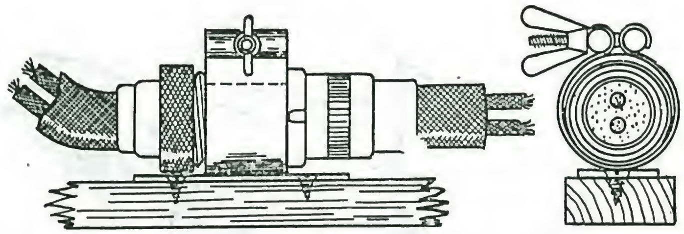




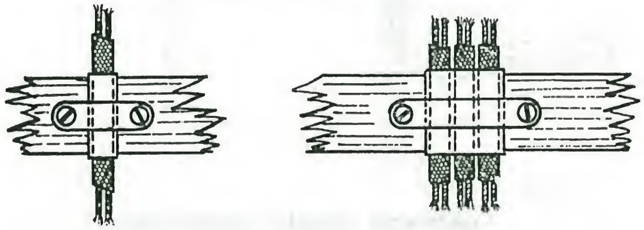
METHOD OF WIRING IN ALL METAL AIRCRAFT.

METHOD OF CARRYING CABLES THROUGH PLANES.

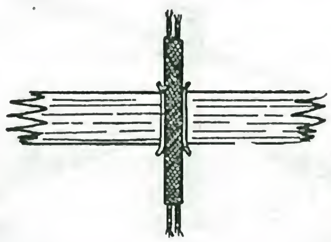
FIG. 82*a*



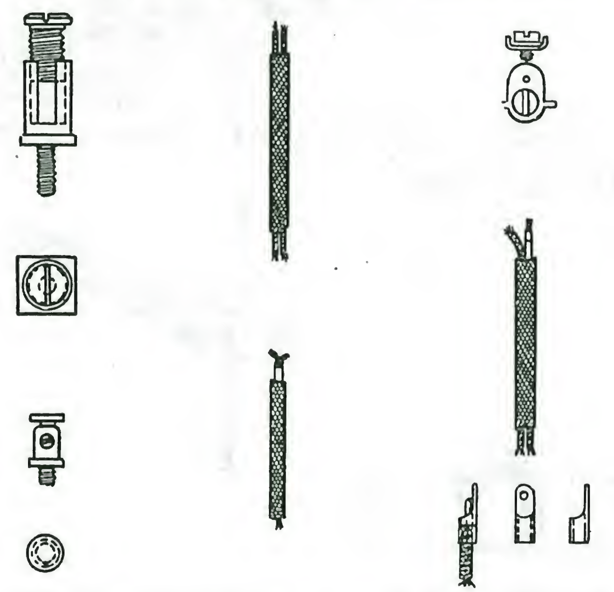
METHOD OF CLIPPING CIRCULAR PLUG AND SOCKET CONNECTORS IN FUSELAGE, WINGS, ETC:



METHOD OF CLEATING ON BATTENS.



METHOD OF BRINGING CABLES THROUGH WOOD.



METHOD OF FIXING CABLE ENDS AT TERMINALS.

FIG. 82*b*

When soldering cable ends to plugs and sockets such as for the generator, care should be taken to apply as small an amount of heat as is necessary for a good joint. Heat destroys the properties of ebonite and bakelite commonly used for plugs and sockets. The fit of the plugs and sockets should be checked after soldering; it will often be found that slackness in the bases, requiring taking-up with a proper tool, has followed this operation.

For soldering, a non-corrosive type of flux, such as resin, should be used; at the conclusion of the operation connections and adjacent ebonite parts which tend to become adhesive and attract metal dust (with a resultant low megger test reading) should be washed in warm water and dried.

Soldered cable ends are not permitted with—

1. Cylindrical holes and grub screws.
2. Terminals consisting of a circular hole with diametral slot, a central screw with large head and a washer.

A soldering thimble consisting of a thin copper tube passed over the end of the cable and spot soldered is used on all items of electrical equipment where the grub screw method of attachment of the cable is employed.

Examination consists, of course, in the general verification of the foregoing. Cables should be examined periodically to ensure that the insulation has not been damaged by contact with moving parts or persons and has not deteriorated from petrol, oil, sea water, dampness, wear and tear, or other cause. The cleating should be inspected to see that no damage has occurred as the result of vibration. The insulation tests which are later described will also give an indication of the general condition of the cables. See that—

(*a*) These general service circuits are, as already instructed, kept as remote as possible from other circuits especially W/T and D/F, in order to reduce risk of interference with external communications; and that in no circumstances have common runs or ducts been adopted.

(*b*) Where aluminium or duralumin tubes or ducts are used for the accommodation of cables they are suitably protected against corrosion.

(*c*) All wiring is suitably marked as necessary to facilitate identification.

(*d*) All cables are free from joints of any description except where terminal blocks or other approved means, adequately protected, are employed.

(*e*) Where cables having an absorbent covering are used and any part of the cable is or could come in contact with the aircraft structure (conduits or ducts are not regarded as parts of the structure) such parts of the cable are separated from the aircraft structure by a non-hygroscopic medium. (Systoflex or material of a like nature is suitable for this purpose.)

(*f*) All cable ends are properly prepared.

(*g*) The rubber and other outer coverings of wires and cables are not allowed to come into contact with dope, petrol, oil, or similar preparations having a deleterious effect thereon.

(*h*) A non-corrosive flux has been used for any soldering.

(*i*) The conductors or cables are free from stress where they are attached to terminals or other fittings, and that the body of the cable is securely clamped at a point as near as possible to the terminal or fitting by means of a suitable clip.

(*j*) Where an insulating separator is required between two metallic bodies, no process which tends to reduce the efficiency of the insulator as such is used. The use of any metallic oxide paint or metallic dope is prohibited. (Soaking of the insulator in paraffin wax or varnish is permitted.)

23. GENERAL ELECTRICAL PARTS, COMPONENTS, AND ACCESSORIES

Switches

There are three kinds of switches in common use, knife, rotary, and tumbler; they are used for making and breaking electrical circuits. They should be arranged easy of access but beyond the possibility of accidental operation. The influence of gravity upon knife switches should be to make them remain off when "open," and not fall into contact.

The action of most switches is accelerated by the incorporation of spring "snap" devices which prevent prolonged arcing but nullify any hesitancy of operation.

The switches should be of ample proportions to deal with the current in the particular circuit, and all movable current-carrying parts should make good electrical contact. There should be no sloppiness in jaws or hinges; faulty contact will cause burning of the parts and result in flickering or failure of the service controlled.

Fuses

Fuses must be installed in all electrical circuits other than engine starters and magneto ignition. They must be of the enclosed type and projected against accidental damage and the terminals against accidental contact; they must be suitable for the kind and size of circuit into which they are inserted to protect. Fuse boxes, groups, or items, should be located where the fuses can be attended to and replaced easily. Fuses should be examined for signs of overheating, which may be due to overloading of the circuit or to poor electrical contact with the fuse clips. A blown fuse should be replaced by one of the same current capacity after having investigated the cause of the blowing. Heavier or lighter duty fuses than the correct ones would be dangerous in a circuit: the latter will readily blow and the former probably cause rupture of the circuit.

Terminal blocks and distribution boxes usually have a base of insulating material upon which are mounted the terminals to which the cables are attached for the linking up of the various circuits. The terminals should be properly separated and at the correct distance apart. The screwed devices should bear well upon the cable ends and be secured so they will not slack off. The terminals should be kept covered to prevent damage and accidental earthing or short-circuiting of the phases by conductive material coming into contact with them.

Plugs and Sockets

Should make good electrical contact, cable ends being securely attached to their terminals. Points of exit and entry of the cables should be examined as regards wear and tear. Neither fuses nor plugs and sockets should be put into or taken out of circuit with the current on. The circuit should be broken by switch and only "made" again when the fuse or plug has been inserted.

Voltmeters and Ammeters

These are not normally repairable outside the maker's factory. The cable connections to the instruments should be examined to ensure that they are correctly, firmly, and securely connected. Any zero error should be corrected by means of adjusting screws where fitted.

Navigation Lights

Are usually so constructed that they can be easily removed from the aircraft when not required. A plug is usually embodied in the base of the lamp. which is inserted into a socket permanently fixed to the aircraft, the socket being connected in the electrical system. The pins should fit the sockets in such a manner as to ensure good electrical contact, and the lamp fitting must be quite secure when fixed in position, the fixing gland nut being lubricated occasionally to prevent tightness. A weather-proof cap should be fitted over the socket when the lamp fitting is removed. The lights, green starboard, red port, and white tail (white head, also, in the case of aircraft under way on water) should be kept clear and unobscured.

Navigation lights must be tested for illumination, alignment, and angle of visibility. If the illumination is doubtful the cause is probably poor electrical connection in the plug and socket fitting or the lamp may be aged. If all lamps show poor illumination it may be due to low voltage at the battery or to a bad switch contact. Navigation lights should always be fitted with the correct lamp bulbs, otherwise the required range of vision may not be obtained.

In craft of less than 65 feet span one or more lamps centrally situated may take the place of those here mentioned.

Identification Lamps and Switchboxes

The glasses of the lamps should be clean. Seating rings should be in good condition. Covers should be secured tightly by their clamps. The switchboxes should be maintained in good working order. Where applicable the key spring should be adjusted as required and the fulcrum of the morse key occasionally oiled with a drop of machine oil. The key contacts should be kept clean and flat; if the points become burned or pitted they should be cleaned with a fine file or emery paper. The switch contacts should be cleaned periodically by wiping with a vaselined rag.

Landing Flares

The ignition circuit must include a double-pole master switch or double-pole firing push buttons with long travel and guarded against accidental operation; or it must incorporate some other approved arrangement that will guard against accidental operation of the flares.

The wiring should be arranged to minimize the risk of its becoming energized by other circuits in the event of an accident.

The flares must be mounted upon proper brackets, the construction and position of which must be such that the glare will not interfere, directly or by reflection in the windscreen, with the pilot's vision, and that the flame will be prevented from overheating the wing or aileron fabric when the aircraft is in flight or standing on the ground. If necessary, metal sheathing must be used as a protective medium.

Flares should be examined for apparent swelling of the content, deterioration of the outer case, and entry of water or any foreign substance through the sealing compound of the fuse element at the top of the flare. An electrical continuity test should be made to ensure that the fuse is intact. Flares or igniters should not be used after the date specified thereon. Flares should be stored under suitable conditions when not in use and should be protected from weather, dampness, and undue heat. Before a flare which has been carried is returned to store, it should be wiped with a dry cloth. The practice of carrying an unused and unprotected flare in its bracket for any considerable period of time is inadvisable;

the effects of damp atmosphere and rain, especially under flying conditions, are harmful, and in an extreme case may result in either dangerously irregular burning or total failure upon attempts of ignition being made. Flares should not, therefore, be fitted to the aircraft until immediately before a particular flight upon which it is anticipated they will be required. Owing to the possibility of accidental ignition it is advisable that flare leads should be disconnected before placing the aircraft in an hangar.

Typical Landing Flare Bracket Used on Seagoing Aircraft

The landing flare bracket is designed to release the flare, when burning, just behind the actual landing point on the water, to avoid risk of the flare igniting oil or fuel under the machine when it comes to rest. The release is only a matter of seconds before landing. To fit the flare, insert the lugs into the contact holder, fit the hook of the wind vane on to the flare loop and pass the release strip through the slot in the guide and secure the end by the wing nut. When burning, the heat will release the strip from the flare, and the wind vane, kept in an upright position by wind pressure, will hold the flare. On losing speed the wind vane will drop forward until, before the machine actually lands, it drops sufficiently to release the flare from the bracket.

Care should be taken when testing these fuses not to use a lamp taking a greater current than ·15 of an ampere, otherwise there is a danger of igniting the flare.

Landing Lamps

Are usually of a special design to suit a particular aircraft. They are, of course, on the accumulator circuit to prevent fading as the aircraft loses speed.

Lamp Fittings

The lighting arrangements should be kept clean. Lamp bulbs should be a good fit in their holders. Bulbs which show signs of blackening should be replaced.

Inspection Lamps

Examine the insulation of the wandering lead; the lead should be replaced if showing signs of abrasion.

Dimmer Devices

Where these are fitted, the rheostat should be tested for good contact between the switch arm and the resistance wire. A steady variation in light should be obtained as the dimmer is moved over its range of operation.

Heating Arrangements

Examine the apparatus for general condition. See that the elements are sound. Flexible leads should be in good condition with no signs of abrasion or stress at any of the plugs and socket fittings. The plugs and sockets should fit in a manner that will ensure good electrical contact. Devices which may be incorporated for preventing the accidental pulling apart of the connected plugs and sockets should be in good order. Any signs of over- or underheating should be immediately investigated. The surroundings adjacent to such heating arrangements should be adequately insulated against fire and scorching, and such insulation should be well maintained. No inflammable material may be within the vicinity and no

petrol or the like carried thereabouts whether in pipes, containers, or otherwise.

The various circuits should be tested separately for continuity. The current consumption of each section should be checked if any defect is suspected. If rheostats are incorporated they should be tested to ensure that heating can be reduced as required.

General Tests

The full electrical equipment must be in accordance with the aircraft maker's instruction and diagrams. The installation should be tested from time to time. The tests comprise Insulation, Resistance, Correct connections and continuity, and Functioning.

The results of all tests should be recorded. By logging such periodic tests any gradual deterioration of the insulation can be detected and steps taken to prevent a breakdown. Apparatus which is connected to the fixed wiring of the aircraft such as generators, portable lamps, heaters, etc., should be tested separately for insulation.

The minimum figure for such apparatus is one megohm, for generators a minimum of 40,000 ohms is acceptable. The test must be made with a 500 volt megger or other suitable instrument and the insulation resistance of all circuits must be tested between poles and between each pole and earth. The minimum results to be obtained are, for wire circuits—

$$\text{No. of megohms} = \frac{20}{\text{number of points in the circuit}}.$$

The minimum value of the insulation resistance obtained by this formula is to be taken as 2 megohms. Switches (which must be closed in the circuit under test), terminal blocks, and other connected apparatus are to be counted as "points." The tests must be made with all switches in running position and the generators and batteries disconnected. All lamps must be removed from their sockets and all detachable plugs leading to heating units or other apparatus should be disconnected.

The insulation test in each instance must be maintained for not less than one minute.

(*Note.* Should the aircraft not be fitted with a voltage control box the leads stated will be found to be connected to a distribution terminal usually on or near the electrical control panel. The aircraft maker's appropriate diagram will indicate the position of this distribution terminal. The leads should be disconnected and the tests proceeded with as described.)

Test for Insulation Between Poles of all Battery Circuits

All leads normally connected to the red terminal of the voltage control box are brought together and connected to one pole of the megger, the other terminal being connected to the negative terminal at the voltage control box-blue. If the figure obtained as the result of this test is not satisfactory it will be necessary to separate the leads at the voltage control box and test each circuit separately until the faulty one is discovered. Action is then to be taken to trace and remedy the fault.

Test for Insulation Between Poles of the Generator Circuit

This test is similar to the foregoing except that the megger terminals are connected between the bunched leads from the yellow terminal and the bunched leads of the blue terminals of the voltage control box.

Test for Insulation Between Positives

This test is similar to that given "between poles" except that the megger terminals are connected between the bunched leads from the red terminal and the bunched leads from the yellow terminal of the voltage control box. It will be noticed that in this case the leads are components of different circuits and it will be impossible to arrive at a denominator for the formula; the figure 6 should therefore be assumed for the purpose.

Test for Insulation Resistance to Earth

For the purpose of this test all wires connected to all terminals of the voltage control box are bunched together and connected to one terminal of the megger; the other megger terminal is to be placed in good contact with the general earth system of the aircraft. If the result is unsatisfactory it will be necessary to separate the various circuits and test each separately until all faults are located and rectified. It will be understood that for the purpose of the first three of the above tests it is necessary temporarily to disconnect the various leads from the terminals of the voltage control box, which must not be in circuit during testing.

The insulation resistance will vary with atmospheric and other conditions and the standard obtained may be higher than that mentioned.

Testing for Correctness of Connections and Continuity

All wiring should be tested from point to point with a battery and lamp or bell, with suitable leads. The smaller sizes of cable should be placed under slight tension during the course of this test to separate possible broken parts which may be just touching.

Should this test indicate any fault it will not only be necessary to rectify it but the insulation tests must be repeated so far as the affected circuit is concerned.

Functioning Tests

An accumulator of suitable voltage should be temporarily connected to the normal accumulator leads and all switches and other control items on the normal accumulator branch operated several times to ensure that each branch of the system is working satisfactorily and is unaffected by the working of any other circuits; this will test the accumulator side. To test all circuits on both branches, the accumulator should be connected as for the battery branch, but in this case the generator leads should be disconnected at the generator end, and the plunger of the battery cut-out held up by hand. In this test all circuits on both branches should be operative.

General Remarks

Aircraft general electrical systems are Direct current; pressure is customarily limited to 14 volts to minimize fire risk and other dangers attendant upon the use of higher voltages; high current densities, however, occur, and care should be taken therefore that the size of all conductors is ample and that all joints are well made and have generous contact areas, otherwise heating will take place.

For reasons of the nature of the demand, to prevent whole or partial non-availability of essential lighting, etc., and to reduce the heavy discharge from one (the accumulator) in the case of slowing down or failure of the other (the generator) the load is derived from two sources—that of heating, etc., being the generator, and that of the navigation, signalling,

landing lights, etc., and any other service where continuity of supply is vital, being the accumulator. Generators, accumulators, wiring, conduits, runs, layouts, switch and fusing gear, electrolytes, insulation, joint boxes, protective treatment, or anything else should never be changed in type or anything added or taken away from the total system without reference to the aircraft maker. The compass is affected by the nearby presence of electrical apparatus and the possibilities of stray magnetic fields from apparatus or cables interfering with its correct functioning should be borne in mind. For example, the following are considered the minimum safe distances between the compass and such apparatus—

1. Kw. full load generator 6 feet; generator 500 watts full load 4 feet; generator 250 watts full load $3\frac{1}{2}$ feet; voltage regulator 40 amps. battery load $3\frac{1}{2}$ feet; twin cables carrying 40 amps. 1 foot; single cable carrying 40 amps. 8 feet; single cable carrying 20 amps. 6 feet; single cable carrying 10 amps. 4 feet.

Notices and signs concerning the electrical system should never in any circumstances be removed or obliterated.

No manner of work involving the shedding of metal filings, etc. the splashing of metallic paint, or the bestrewing of material which may act as a conductor of electricity, should ever be done in the vicinity of electrical gear without previously covering over such gear with a cloth, etc., which may be afterwards gathered and shaken clear of the aircraft.

Ample protection should be afforded all parts of electrical installation against water, petrol, oil, or spray.

(Figs. 71, 73–80, and 82 in this chapter are reproduced from *A.P.* 1095, by kind permission of the Controller, H.M.S.O.)

APPENDIX I

CERTIFICATE OF SAFETY FOR FLIGHT

I HEREBY CERTIFY that I have this day inspected the above aircraft (including its instruments and equipment but exclusive of the engine(s) and engine installation and of the instruments relating thereto) and that I am satisfied that it is safe in every way for flight, provided that the conditions of loading specified in the certificate of airworthiness are complied with.

The time this inspection was completed was 0900 hours.

Signed HERBERT BROWN.
Ground Engineer "A" Licence No. 10008.

Date: *November* 30*th*, 1933 Time: 1030 hours.

(Extract from *Air Navigation Directions*)

APPENDIX II

Serial No. 745

ADVICE AND RELEASE NOTE

Issued under Air Ministry Authority
Reference No. 654321/30

Harry Jones's Aircraft Works, Ltd.

NORTHEASTCHESTER

ENGLAND

Telephone: 999 Telegrams: "AEROPLANES."

Please note the following have been dispatched—	Contract No.
Consignee— The Starland Aerial Transport Co., Ltd. Lowland Aerodrome, Nr. Highover, Hants.	Order ref. No. ZA 313

Item No. of Contract or Order	Description of Goods including Part and Drg. Nos. and/or Specn. No.	Quantity	Identification	Remarks
5	STRUT, INTERPLANE 194/AC.531	1	4J21	Order Complete
12	PLATES, WIRING 2001/A3C 211	4	4J33	

CERTIFIED that the whole of the material and/or parts detailed hereon have been inspected and tested in accordance with the conditions of

The Air Navigation Directions

and the general requirements of the Director of Aeronautical Inspection and that they conform with the drawings and specifications relative thereto.

Signed K. N. RICHMOND,
Chief Inspector, HARRY JONES'S AIRCRAFT WORKS, LTD.

Date: November 23rd, 1933.

APPENDIX III

(1) LIGHT ALLOYS

Material	Form	Specification	Composition: Base	Composition: Alloying Metals	Tensile Strength tons/sq. in.	Remarks	Used For
Duralumin	Sheet and strip	B.S.S. 3.L.3	Aluminium	Copper Manganese Magnesium	25	Bend radius = 2t. To be anodically treated	Hulls, floats, and fittings. Spars and ribs
,,	Bar	B.S.S. 3.L.1	,,	,,	,,	,,	Machined fittings
,,	Tubes	B.S.S. 3.T.4	,,	,,	26	,,	Fuselage and ribs
Aluminium	Sheet and strip	B.S.S. 2.L.16	,,	None	$7 - 8\frac{1}{2}$	Half hard. Bend radius – 1/2t.	Tanks and fairings
,,	Bar	B.S.S. 3.L.4	,,	,,	5	Bend radius 1/2t.	Tank fittings
,,	Tubes	B.S.S. 3.T.9	,,	,,	10	—	Pipe lines
Alclad	Sheet	D.T.D. 111	Duralumin—coated uniformly on both sides with pure aluminium		24	—	Hulls, floats, fittings, spars, and ribs
Alpax	Castings	B.S.S. L.33	Aluminium	Silicon	$10\frac{1}{2}$	For sea-going craft	Various fittings
Aluminium copper zinc alloy	Castings	B.S.S. 3.L.5	,,	Copper zinc	9	For land machines	Various fittings
Aluminium copper alloy	,,	B.S.S. 3.L.8	,,	Copper	7	For unimportant parts	Various fittings

(2) STAINLESS STEELS

Material	Form	Specification	Composition Base	Composition Alloying Metals	Tensile Strength tons/sq. in.	Remarks	Used For
12% Chromium steel	High tensile strip	D.T.D. 46.A	Iron	Carbon Chromium	Max. stress not specified 0·1% proof stress = 65.	Bend radius = 3t for 24G and thinner material 5t for thicker material.	Spars and ribs
12% Chromium steel	Bar	B.S.S. S.62	,,	Carbon nickel Chromium	46–52	Brinell hardness, No. 207–235	Machined fittings
12% Chromium steel	Tubes	D.T.D. 105	,,	,,	50	—	Struts
12% Chromium steel	Sheet	D.T.D. 23B	,,	,,	30–40	Bend radius = 1/2t.	Fittings
20% Chromium 2% Nickel steel	Sheet and strip	D.T.D. 60A	,,	Carbon nickel Chromium	55	Hardened and tempered condition	Fittings
,,	,,	D.T.D. 146	,,	,,	40	Softened condition	Fittings
,,	Bars	B.S.S. S.80	,,	,,	55	Brinell hardness, No. not less than 241.	Machined fittings
,,	Tubes	D.T.D. 199	,,	,,	50	—	Struts
,,	High tensile strip	D.T.D. 168	,,	,,	75	Bend radius = 3t.	Spars and ribs
18% Chromium 8% Nickel steel	Sheet and strip	D.T.D. 171A	,,	,,	35	Bend radii: for material thinner than 10G—closed down flat 10G, and thicker 1/2t.	Fittings. Hull plating.
,,	Bar	D.T.D. 176A	,,	,,	35	—	Machined fittings
,,	High tensile strip	D.T.D. 166	,,	,,	52–70	Bend radius = 1t.	Spars and ribs Hull plating
,,	Tubes	D.T.D. 207	,,	,,	35	—	Struts

(3) PLAIN CARBON STEELS

Material	Form	Specification	Composition Base	Composition Alloying Metals	Tensile Strength tons/sq. in.	Remarks	Used For
Mild steel	Sheet	B.S.S. 2.S.3	Iron	Carbon Manganese	28	Bend radius = 1/2t. Normalize after welding.	Fittings
,,	Bar	B.S.S. 3.S.1	,,	,,	35–45	,,	Machined fittings
,,	Tubes	B.S.S. 2.T.1	,,	,,	35	,,	Struts
,,	Castings	D.T.D. 17.A	,,	,,	26	,,	—
Low carbon steel	Sheet	D.T.D. 12.A.	,,	,,	22	Bend radius = 1t.	Exhaust manifolds
High tensile steel	Wires	B.S.S. S.W.3	,,	,,	52–65	Bend radius = 3t.	Streamline wires
			(4)	VARIOUS STEELS			
Manganese steel	Castings	D.T.D. 9.B	,,	Carbon Manganese	Not specified	Brinell hardness not less than 241	Skid shoes
Nickel chrome steel	Strip	D.T.D. 54.A	,,	Carbon nickel Chromium	Not specified 0·1% proof stress—65.	Bend radii: 24G and thinner = 3t. Thicker than 24G = 5t	Spars and ribs
Nickel chrome steel	Tubes	B.S.S. 2.T.2	,,	,,	85–110	Must not be heated or drilled	For axles
Tinned steel	Sheet	B.S.S. 3.S.20	,,	Tinned on surface	Not specified	Bend radius = flat	Tanks
High carbon steel for	streamline wires	and tie rods.					

(4) COPPER ALLOYS

Material	Form	Specification	Composition Base	Composition Alloying Metals	Tensile Strength tons/sq. in.	Remarks	Used For
Copper	Sheet	B.S.S. 2.B.15	Copper	None	14–19	Bend radius—Closed down flat—Half hard	Tanks
Brass	Sheet	B.S.S. 2.B.16	,,	Zinc	24–30	,,	Tanks
,,	Bar	B.S.S. 3.B.1.	,,	,,	35	—	Machined parts
Gunmetal	Castings	B.S.S. 2.B.2	,,	Zinc and tin	16	—	Fittings
,,	Bar	D.T.D 155	,,	,,	35	—	Machined parts
Monel metal	Sheet	D.T.D. 10.A	Nickel	Copper	30	Bend radius closed down flat	Tanks Float plating
			M	ISCELLANEOUS			
Solder (Silver) hard	—	B.S.S. 206/1924	Silver	Copper and zinc	—	—	General
Solder soft	—	B.S.S. 219/1922	Lead Tin	—	—	—	General
Brazing metal	—	B.S.S. 263/1931	Copper	Zinc	—	—	General

APPENDIX IV

GLOSSARY OF AERONAUTICAL TERMS

Abstracted by permission from "British Standard Glossary of Aeronautical Terms," copies of which can be obtained from the British Standards Institution, 28 *Victoria Street, London, S.W.*1.

Airworthy. Complying with the prescribed regulations for a certificate of airworthiness.

Ground Engineer. An individual authorized to certify the safety for flight of an aircraft or parts thereof in accordance with the regulations for the time being in force.

Nose Heaviness. A tendency of an aircraft to pitch down by the nose in flight.

Tail Heaviness. A tendency of an aircraft to pitch down by the tail in flight.

Flutter. An unstable oscillation due to the interaction of aerodynamic and elastic forces upon the inertia of any structure.

Air Speed. Speed relative to the air, as distinct from speed relative to the ground.

Indicated Air Speed. The product of the air speed and square root of the relative air density (V_i).

Note. This definition will agree with readings taken by a pressure head only until the effect of compressibility becomes noticeable.

Range. The maximum distance an aircraft can travel under given conditions without refuelling.

Streamline. The path of a small portion of a fluid, assumed continuous, moving relatively to a solid body. The term is commonly used only of such paths as are not eddying, but the distinction should be made clear by the context.

Aeroplane. A flying machine with fixed wings.

Amphibian. An aeroplane provided with means for normally rising from and alighting on either land or water.

Landplane. An aeroplane provided with means for normally rising from and alighting on land.

Seaplane. An aeroplane provided with means for normally rising from and alighting on water.

Float Seaplane. A seaplane provided with floats as its means of support on water.

Flying Boat. A seaplane of which the main body or hull is also the means of support on water.

Monoplane. An aeroplane or glider with one main supporting surface.

Multiplane. An aeroplane or glider with two or more main supporting surfaces one above another.

Biplane, Triplane. *Note.* Monoplane, Multiplane, Biplane, and Triplane are also used as adjectives associated with a particular component, e.g. Biplane rudder, Triplane tail, etc.

Pusher Aeroplane. An aeroplane in which the airscrew is mounted in rear of the main supporting surfaces.

Ship-plane. Any aeroplane specially adapted for rising from and alighting on a ship's deck.

Tractor Aeroplane. An aeroplane in which the airscrew is mounted in front of the main supporting surfaces.

Aerofoil. A surface designed to produce an aerodynamic reaction normal to the direction of motion.

Slotted Aerofoil. An aerofoil having an air passage (or slot) rearwardly directed from its lower to its upper surface. This slot is so shaped that the portions of the aerofoil separated by it are themselves of aerofoil section. When the slot is forwardly located the portion forward of the slot forms an auxiliary aerofoil which may be rigidly attached to the rear portion or be capable of movement relative to it.

Slat. An auxiliary aerofoil forming the forward portion of a slotted aerofoil with forwardly located slot.

Aerofoil Section. The outline of the section of an aerofoil in a plane parallel to its plane of symmetry.

Aileron Angle, Elevator Angle, Rudder Angle. The angle between the chord of the movable portion of an aerofoil and the chord of the corresponding fixed surface.

Angle of Incidence (Rigging). The angle between the chord line of the main plane and the horizontal when the aeroplane is in the rigging position.

Note. Not to be confused with the true angle of incidence.

Angle of Sweep-back. The angular set back of the main planes relatively to the fuselage or hull.

Dihedral Angle. The angle at which both port and starboard planes of an aeroplane or glider are inclined upwards or downwards to the transverse axis. The dihedral angle is the acute angle between the span axis of either plane and the transverse axis. If the inclination is upwards the dihedral is positive.

Tail Setting Angle. The acute angle between the chord line of the main plane and the chord line of the tail plane. If the latter is at a greater inclination to the horizontal than the former the angle is said to be positive.

Camber. Curvature of a surface of an aerofoil.

Chord or Chord Length. The length of that part of the chord line which is intercepted by the aerofoil section.

Chord Line. The chord line is the straight line through the centres of curvature at the leading and trailing edges of an aerofoil section.

Gap. The distance between a plane and the one immediately above and below it.

Leading Edge. The forward edge of a streamline body or aerofoil. The structural member there situated.

Overhang. 1. The extent to which the wing tip of one of the two superimposed planes projects beyond the tip of the other.

2. The distance from the outer point of support to the tip of an aerofoil.

Rigging. The relative adjustment or alignment of the different components of an aerodyne.

Rigging Position. The position in which, with the lateral axis horizontal, an arbitrary longitudinal datum line is also horizontal.

Span. The overall distance from wing tip to wing tip.

Semi span. The distance from the tip to the plane of symmetry of an aerofoil.

Stagger. When one of two superposed planes is disposed ahead of the other, the planes are said to be staggered. When the top plane is ahead of the bottom the stagger is said to be positive.

Trailing Edge. 1. The rear edge of a streamline body or aerofoil.

2. The structural member there situated.

Wash-in. Increase of angle of incidence towards the wing tip.

Wash-out. Decrease in angle incidence towards the wing tip.

Airframe. An aeroplane with the engine(s) removed.

Doping. Treatment for the purpose of protecting tautening, strengthening or rendering airtight a surface.

Aero-structure. The supporting and controlling surfaces of a flying boat.

Ailerons. Movable flaps situated at or near each wing tip and designed to impart a rolling motion to the aerodyne by their rotation in opposite senses.

Floating Ailerons. Port and starboard ailerons so connected that, under the action of air moments, alone, they are free to take up an equilibrium without relative angular displacement. They are operated differentially in the normal manner through the control column.

Balanced Surface. A control surface which extends on both sides of the axis of the hinge or pivot in such a manner as to reduce the moment of the air forces about the hinge. The portion of the surface in the front of the hinge is referred to as the "balance" or "balance portion."

Horn Balance. The balance is confined to the tip of the control surface and extends beyond the fixed surface.

Centre Section. The central portion of the main plane (top or bottom).

Elevator. A movable horizontal surface for controlling the motion of an aerodyne in pitch.

Fin. A fixed vertical surface affecting the lateral stability of the motion of an aerodyne. When fitted at the rear end of the body it is termed the tail fin.

Flap. A hinge rear portion of an aerofoil.

Levers. Aileron Lever, Elevator Lever, Rudder Lever. The lever arm by which the control surface is connected to the actuating mechanism.

Planes. Main Plane. A supporting surface of an aerodyne, including ailerons.

Rudder. A movable vertical surface for controlling the motion of an aerodyne. in yaw.

Servo Control. A control devised to reinforce the pilot's effort by an aerodynamic or mechanical relay.

Stub Plane. 1. A short length of plane projecting from the fuselage or hull (usually forming a part thereof) to which the main portion of the plane is connected.

2. Projections from the hulls of flying boats to give lateral stability on the water.

Tail Unit. The combination of stabilizing and controlling surfaces situated at the rear of an aerodyne.

Chine. The extreme side member of the hull running approximately parallel to the keel in side elevation.

Control Column. The lever, or pillar supporting a hand wheel, by which the elevator and aileron controls are operated.

Adjusting Gear for Aileron, Rudder Fin, or Tail Plane. Mechanism provided for altering the trim of the control surface during flight.

Rudder Bar. The foot bar by means of which the rudder is operated.

Rudder Pedals. An alternative device to rudder bar.

Alighting Gear. That part of an aerodyne (other than the hull of a flying boat) provided for its support on land and water, and for absorbing the shock on alighting. In addition to the undercarriage. alighting gear includes subsidiary items such as tail skid, wing tip skids. and floats.

Float. A water-tight body giving buoyancy and stability on the water to a seaplane or amphibian and enabling it to take off and alight.

Flotation Gear. Emergency flotation appliances for landplanes.

Step. A break in the under-surface of a float or hull designed to facilitate take-off.

Tail Skid. A member taking the weight of the rear end of the fuselage on the ground.

Tail Skid Bar. The crosspiece on a steerable tail skid.

Tail Skid Shoe. A replaceable covering on the end of a tail skid to take the wear.

Tail Wheel. A small wheel sometimes fitted in place of a tail skid.

Undercarriage. That part of the alighting gear which embodies the main wheels, skids, or floats.

Acorn. A device introduced at the intersection of bracing wires to prevent abrasion.

Strut. A structural member intended to resist compression in the direction of its length.

Drag Struts. Struts incorporated in the framework of an aerofoil to carry the loads induced by the air forces in the plane of the aerofoil.

Interplane Struts. Vertical or inclined struts connecting the spars of a plane to those of the plane above.

Jury Strut. A strut inserted to provide temporary support for a structure. A common example is the strut used to support the wing structure of an aerodyne during folding.

Wires. *Drag Wires.* Wire or cables the principal function of which is to transfer the drag of the planes to the body or other part of the structure.

Anti-drag Wires. Wires to resist forces in the opposite direction to the drag.

Incidence Wires. Wires or cables bracing the main plane structure in the plane of a pair of front and rear struts.

Lift Wires. Wires or cable the principal function of which is to transfer the lift of the wings to the body or other part of an aerodyne.

Anti-lift Wires. Wires to resist forces in the opposite direction to the lift.

Flying Weight. The total weight of an aircraft at the beginning of a flight.

Gross Weight. The maximum flying weight of an aircraft permissible under the regulations obtaining.

Note. For Civil aircraft this is the maximum authorized weight shown on the Certificate of Airworthiness.

Tare Weight. The weight of an aerodyne complete in flying order with water in the radiators, but no crew, fuel, oil, removable equipment or pay load.

Airscrews. 1. Generically, all types of screw with helical blades designed to rotate in air.

2. Specifically, a power driven screw designed to produce thrust by its rotation in air.

Pusher Airscrew. An airscrew designed to produce compression in the airscrew shaft.

Left-hand Airscrew. An airscrew revolving counter-clockwise to an observer behind the aircraft.

Right-hand Airscrew. An airscrew revolving clockwise to an observer behind the aircraft.

Note. In the tractor system the "hand" of the airscrew is the same as that of the engine, but in the pusher system it is the opposite.

Variable Pitch Airscrew. An airscrew whose blades are so mounted that they may be turned about their axis to a desired pitch while the airscrew is in rotation.

Note. This term is not to be used for an airscrew whose blades are adjustable only when stationary.

Blade Angle. The acute angle between the chord of an element of an airscrew blade and the plane of rotation.

Out-of-Pitch. Having the blade angles of one blade different from those of the other(s) at the same radius.

Boss. The central portion of the airscrew by which it is attached to the airscrew hub or shaft.

Diameter. The diameter of the circle described by the tips of the blades.

Disc Area. The area of the circle described by the tips of the blades.

Pitch. Experimental mean pitch. The distance through which an airscrew advances along its axis, during one revolution when giving no thrust.

Sheathing. Thin sheet metal or other material attached to the tips and leading edges of wooden blades to prevent abrasion by water, sand, etc.

Slipstream. The stream of air discharged aft by a revolving airscrew.

Spinner. A streamline fairing fitted co-axially and rotating with the airscrew.

Static Unbalance. An airscrew is in static unbalance if, when concentrically mounted on a spindle supported by knife edges, it will not remain at rest in all positions.

Torque. The moment about the airscrew axis of the air forces on the airscrew.

Windmill. A device which by virtue of its translational motion relative to the air rotates and so develops power.

Air Speed Indicator. An instrument, the reading on which, subject to certain corrections, gives the speed of the aircraft relative to the air.

Altimeter. An instrument graduated to indicate height under specified conditions.

Cross Level. An instrument for indicating the direction of the resultant force on an aircraft in a transverse plane.

Fore and Aft Level. An instrument for indicating the direction of the resultant force on an aircraft in its plane of symmetry.

Pressure Head. A combination of pitot and static pressure tubes for use in conjunction with a differential pressure gauge for determining the speed of a current of air.

Pitot Tube. A tube with an open end facing a current of air.

Static Pressure Tube. A tube with lateral apertures designed to ensure that the pressure in it shall be static.

Turn Indicator. An instrument for indicating the deviation of an aircraft from its course to port or starboard.

Compass. An instrument for indicating, subject to certain corrections, the angle in the horizontal plane between the true or magnetic meridian and the longitudinal axis of an aircraft.

Aircraft Landing Flare. A pyrotechnic flare normally attached to the underside of an aircraft to enable the pilot to illuminate the earth's surface when alighting.

Aircraft Lighting. The system of lighting on an aircraft.

Navigation Lamp. A lamp on an aircraft for indicating its position and direction of motion.

Riding Lamps. Lamps displayed by aircraft at anchor or when moored.

Signalling Lamp. A lamp for making visual signs.

Compass Base. An area provided with means for orientating aircraft to facilitate the compensation of their compasses.

Drogue. A sea anchor consisting of a conical sleeve, open at both ends, used to check the way of an aircraft.

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INSPECTION OF AIRCRAFT AFTER OVERHAUL

CATEGORY "B" LICENCE

Part II

BY

S. J. NORTON

ASSOC.M.INST.C.E., A.F.R.AE.S.

The Air Ministry, whilst accepting no responsibility for the contents of this book, recognizes it as a textbook that should prove to be of value to intending applicants for Ground Engineers' licences

PREFACE

This instructional work has been prepared as a guide to intending applicants for the Category "B" Ground Engineer's Licence.

Air Ministry Pamphlet 34, which is entitled "Instructions to Applicants for Ground Engineers' Licences and Syllabus of Examinations," is usually sent to every applicant for a ground engineer's licence. It points out that all applicants will be required to show that they have obtained and studied the Air Navigation Order and the Air Navigation Directions issued thereunder, which detail the duties and qualifications of ground engineers, and provide for all concerned information regarding the regulations governing Civil Aviation. It is essential that prospective ground engineers should have a satisfactory knowledge of these regulations.

It further indicates that applicants should obtain the "Airworthiness Handbook for Civil Aircraft" (A.P. 1208), which contains valuable information in connection with the inspection of aircraft and aero engines. The Airworthiness Handbook is of particular importance and value to aspirants for licences in category "B." These publications can be obtained from His Majesty's Stationery Office, York House, Kingsway, W.C.2, or through any bookseller.

The directions require that as regards category "B" the applicant must have had such practical experience on aircraft maintenance and construction as, in the opinion of the Secretary of State, will enable him to perform satisfactorily the duties for which the licence is required.

It is further important that the candidate should understand clearly what duties come within the scope of the particular category in which he is to be examined, as there is the danger of exceeding those duties and overlapping into categories for which he has not been certified.

It must be realized that whereas the category "A" ground engineer is only entitled to replace aircraft components or parts which have been previously inspected and approved, the category "B" man is responsible that such components or parts are made from the correct materials, and that the processes employed in manufacture have been carried out satisfactorily.

For this purpose he must be able to satisfy himself that the materials used in construction comply with the specifications, either by documentary evidence such as approved release notes coupled with inspection and identification stamps on the material, or by the examination of the results of tests which on occasion he may have

to instigate or perform. In some instances, e.g. timber, he may himself be responsible for selecting the material to be used.

During the inspection of an aircraft and its accessories after repair or overhaul, he should ensure that no departure has been made from the type aircraft without official authority.

Another feature demanding attention is that of the category in which the aircraft is certified, such as "Special" or "Normal" categories, coupled with the particular subdivisions of these categories.

The Syllabus for a candidate entering the category "B" examination lays down that to qualify, the candidate should understand the general principles of the inspection of aircraft construction, including the following—

1. Knowledge of non-metallic materials; methods of identification, examination, and testing; characteristic defects which render them unsuitable; and precautions to be observed in their application to aircraft construction.

2. Knowledge of metallic materials; methods of identification, examination, and testing; characteristic defects which render them unsuitable, and precautions to be observed during processes of manufacture (heat-treatment, welding, brazing, soldering, plating, etc.).

3. For licences to include seaplane endorsements, knowledge of the methods of construction and examination of hulls and floats is also required.

4. Knowledge of the methods of construction, examination, and testing of aircraft parts and components (fuselages, wings, propellers, tanks, radiators, pumps, cocks, etc.).

5. For licences to include aircraft of all-metal construction, knowledge of the high tensile steels and aluminium alloys, and the special workshop processes applicable to the materials, is required.

6. Knowledge of methods of inspecting and testing the complete aircraft for correct assembly; installation of engine, controls, fuel, oil, and water systems, instruments, electrical services, and other appliances.

In conclusion it should always be fully realized that the methods of inspection must of necessity vary to keep pace with the improvements in design and construction, and that the ground engineer, to maintain efficiency, must devote the requisite attention to these changes as and when the information relating thereto is circulated.

Copies of D.T.D. Specifications can be obtained through H.M.S.O., Kingsway, London, W.C.2, and copies of B.S. Specifications from The British Standards Institution, 28 Victoria Street, London, S.W.1.

NOTE. Where Specification Numbers are quoted in this volume the latest issues of the Specifications are always implied.

CONTENTS

INSPECTION OF AIRCRAFT AFTER OVERHAUL

CHAPTER I

NON-METALLIC MATERIALS

THE materials used in aircraft construction may be divided into two classes, Non-metallic and Metallic.

Under the heading of non-metallic materials are the timbers, plywoods, fabrics, dopes, glues, rubber and other flexible hose (for use with petrol, oil, and water), varnishes, paints, rubber shock absorber cord, fibre, and leather, for which, with the exception of the last two, there are B.S. or D.T.D. Specifications.

TIMBERS

The timbers used in the construction of composite aircraft are chiefly spruce and ash, while for the construction of wooden airscrews mahogany and walnut are used. In the selection of rough timber in the bulk, attention should be paid to the general characteristics of each piece, with a view, as far as is possible, to selecting a quality which conforms to the applicable specification. Such factors as the method of seasoning; conversion; weight per cubic foot; rate of growth, which is judged by the annual rings; direction of grain; amount of sapwood, and the characteristic defects, must receive due attention at this stage to avoid, as far as possible, the scrapping of parts during manufacture.

Testing of Timber

The tests carried out on timber to ascertain that it complies with the specification, and is suitable for use on aircraft, are as follows—

1. Moisture content test.
2. Density (lbs. per cubic foot).
3. Tests for Young's Modulus, and modulus of rupture.
4. End grain compression test.
5. Brittleness test.

The required minimum results of these tests are laid down in the specifications for the particular timbers, and briefly are as follows—

The methods of determining these results are laid down in the respective British Standard Specifications, and for the benefit of the reader are reprinted in the following pages by courtesy of the British Standards Institution. The methods of carrying out the tests are standard for the timbers already mentioned. (Copies of British Standard Specifications can be obtained from British Standards Institution, 28 Victoria Street, London, S.W.1.)

METHOD FOR MEASURING MOISTURE CONTENT

A small sample of the timber shall be removed from the position indicated by the inspector and weighed (W_1). The sample shall then be

TABLE I

Timber	Specification	Moisture Content	Density (Lbs. per cub. ft. at 15% moisture content)	End Grain Compression (Lbs. per sq. in. strength not less than)	Young's Modulus (Lbs. per sq. in.)	Modulus of Rupture (Not less than lbs. per sq. in.)	Brittleness (Ft. lbs.)		At a Moisture Content of*
							Method A	Method B	
Silver Spruce .	D.T.D. 36.A.	14 to 17%	24	5,000	Not less than 1,500,000	8,000	13	6	15%
Ash .	B.S.S.3.V.4.	Not more than 16%	40	5,800	1,500,000 to 1,900,000	10,500	17	8	15%
Walnut . .	B.S.S.3.V.5.	Not more than 13%	35	7,000	Not less than 1,500,000	11,500	15	7	15%
Mahogany .	B.S.S.4.V.7.	Not more than 14%	32	6,250	Not less than 1,500,000	10,000	8	4	15%

* For test figures at other moisture contents see particular specification.

desiccated in an oven at a temperature of approximately 100° C. to 105° C. (212° F. to 221° F.) until the weight is constant (W_0).

The percentage of moisture shall be calculated as follows—

$$\text{Percentage of moisture} = \frac{W_1 - W_0}{W_0} \times 100$$

For the determination of moisture content of test pieces the sample shall be taken on a transverse section near the fracture.

Great care should be taken to prevent any change in moisture content between the cutting of the sample and the first weighing or between removal from the oven and the subsequent weighing.

Method for Determining End Grain Compression Strength

Three test pieces shall be turned from each sample to be tested.

The test pieces shall be prepared to the dimensions shown in Fig. 1, the ends being turned quite flat, the small centre pip being smoothed off with a chisel; or, alternatively, the test pieces may be cut 1 in. square and 2 in. long. If the faces are not quite parallel, or if the testing machine does not load the sample quite evenly, the sample may be fitted with end collars.

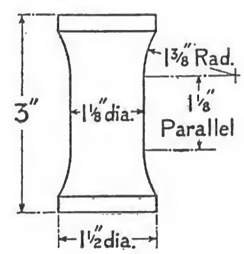


Fig. 1. End Grain Compression Test Piece

(By courtesy of The British Standards Institution)

It should be noted that, if the sample is not loaded evenly, the results will be lower than the true value, and if the load is applied too rapidly the results will be higher than the true value. At the specified rate, the test takes about one minute, and a close watch should be kept on the beam of the testing machine when approaching the maximum load and the loading stopped at the moment the beam begins to drop.

During the test the load shall be so applied that the stress in the test piece increases at a rate of from 3,000 to 6,000 lb. per sq. in. per minute. The ultimate compression stress for the timber shall be taken as the average of the three tests, the corresponding moisture content being taken as an average of the moisture content of the three test pieces.

Method for Determining Young's Modulus of Elasticity and the Modulus of Rupture

The test piece shall be 40 in. long and shall have a rectangular section 2 in. deep by 1 in. wide, or preferably a square section 2 in. by 2 in. It shall be cut with the length parallel to the longitudinal direction of the grain of the timber and preferably with the depth parallel to the radial face of the test piece, the heart side being uppermost.

The beam test should be carried out wherever possible with four point loading in order to avoid additional deflection due to lateral shear in the middle part of the beam where the deflection is measured. The load shall be applied in the neutral plane of the beam in such a manner as to prevent longitudinal loading of the beam and local crushing of the timber, and at such a rate that the loading head descends at a constant speed of 0·13 ± 20 per cent inch per minute. A suitable apparatus is illustrated in Fig. 2.

A series of deflections corresponding to a series of increasing loads should be measured on a portion of the beam between the central loading points. Results when plotted should lie on a straight line up to the elastic limit.

If W_1, W_2, and d_1, d_2 are the loads and corresponding deflections for any two points on this straight line the value of E is given by

$$E = \frac{3\ (W_1 - W_2)}{4\ (d_1 - d_2)} \frac{al^2}{bh^3}$$

where a = distance between the outer point of support and the adjacent inner loading point (see Fig. 3),

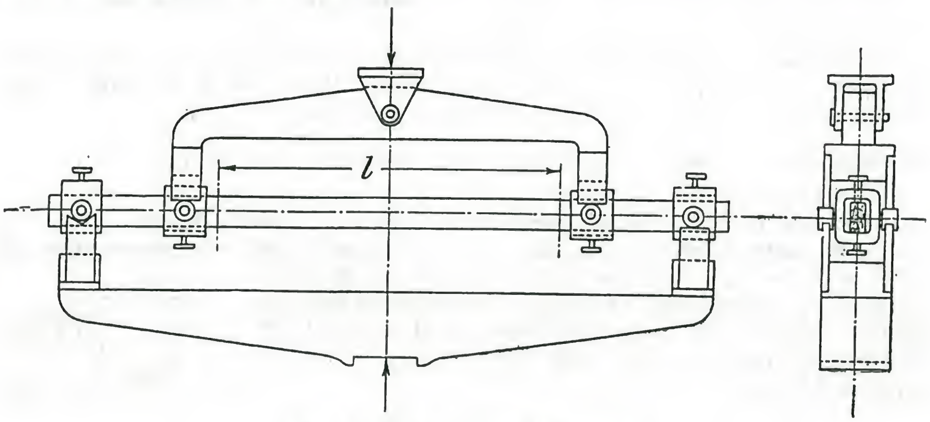


FIG. 2. BEAM TEST MACHINE
(By courtesy of the British Standards Institution)

l = length (of the neutral axis) at the centre of which the deflection has been measured,
b = breadth of beam,
h = depth of beam,
all dimensions being in inches.

The modulus of rupture may be calculated as follows: Modulus of rupture $= \frac{3\ Wa}{bh^2}$ where W is the load required to break the test piece.

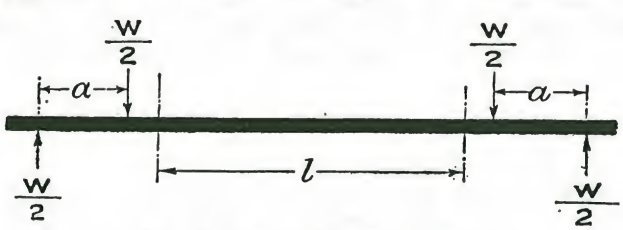


FIG. 3. BEAM TEST DIAGRAM
(By courtesy of the British Standards Institution)

METHODS FOR DETERMINATION OF BRITTLENESS

Method A. A plain test piece, cut parallel to the grain, to the size given in the specification, shall be prepared, with the sides cut radially and tangentially, and the blow shall be applied in the tangential direction.

The testing machine shall consist essentially of a free falling, vertically guided weight of 24 lb., the striking surface of which shall be cylindrical with a radius of 3 in. The weight shall be dropped through 4 in. for Mahogany, 6½ in. for Spruce, 7½ in. for Walnut, and 8½ in. for Ash; on to the above test piece, when the latter is placed centrally on supports 10 in. apart. These supports shall have a ¼ in. radius on the inside upper edges.

The machine shall stand firmly on a concrete floor, or its equivalent. An illustration of a suitable machine is shown in Fig. 4.

IMPACT TESTING MACHINE.

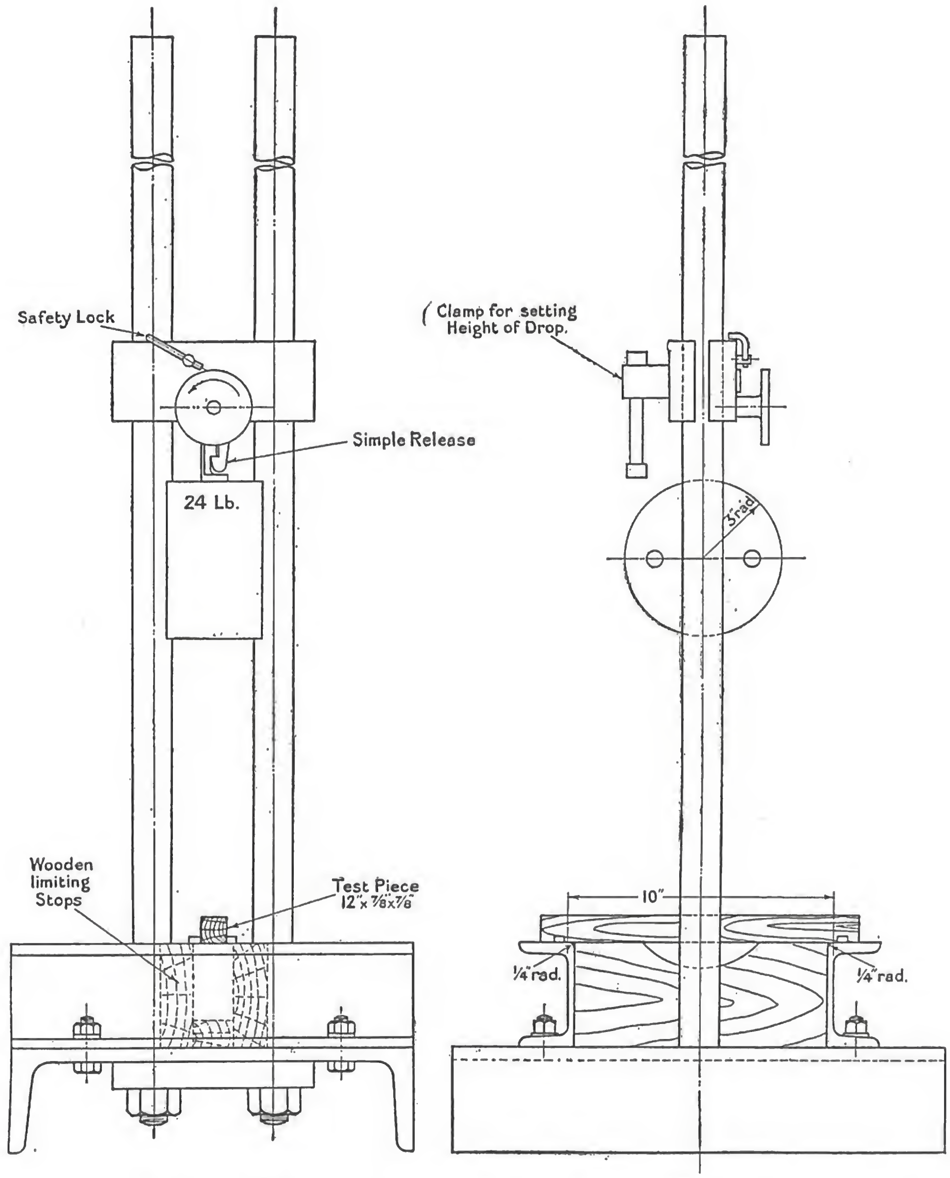


FIG. 4. SIDE AND END ELEVATIONS OF SIMPLE DROP IMPACT TESTING MACHINE

(By courtesy of The British Standards Institution)

The opening out of a few fibres on the under or tension side shall not be taken as indicative of failure.

Method B. A notched test piece, the sides of which are cut radially and tangentially, of the dimensions shown in Fig. 7 shall be broken in an

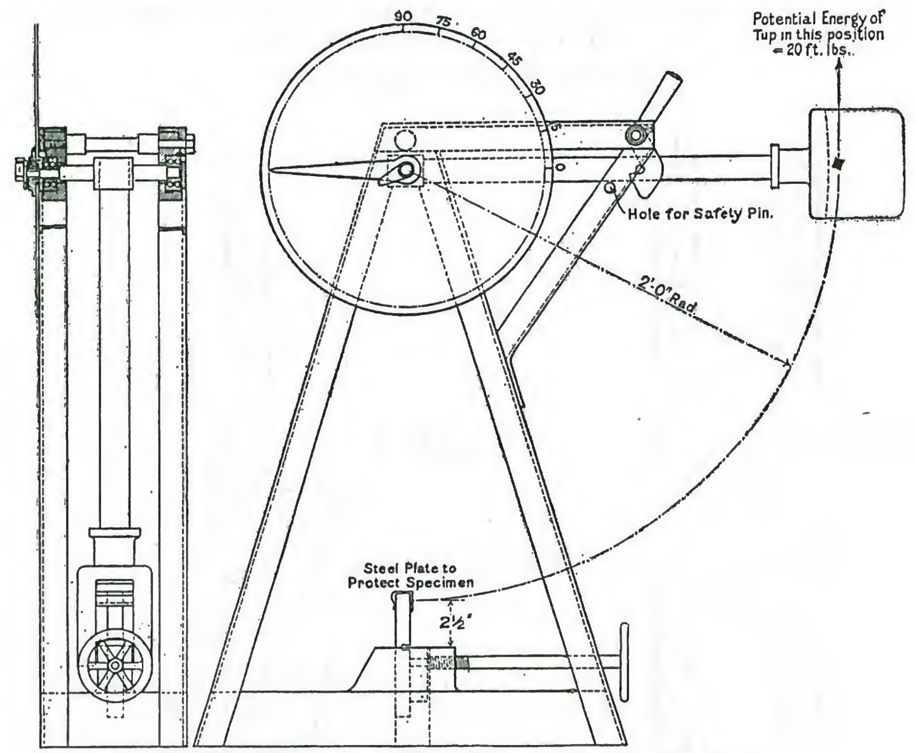


FIG. 5. SIDE AND END ELEVATIONS OF IMPACT TESTING MACHINE

(By courtesy of The British Standards Institution)

NOTE.—When Scale is marked in Degrees as shown, work expended in breaking specimen = 20 sin α (α = reading on scale at which Pointer comes to rest).

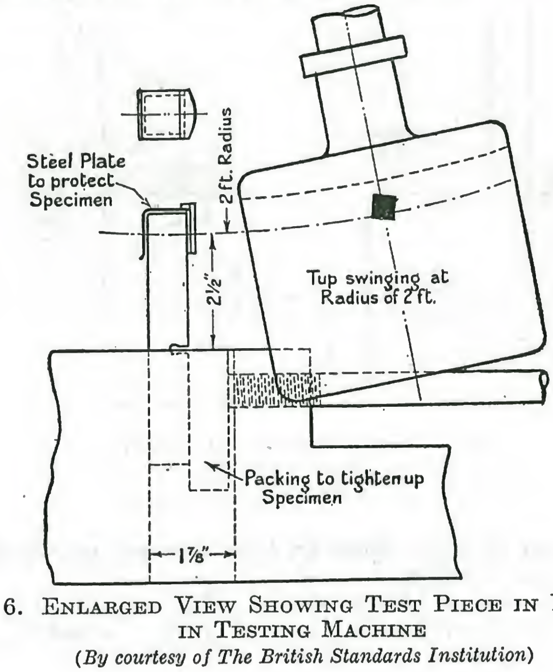


FIG. 6. ENLARGED VIEW SHOWING TEST PIECE IN POSITION IN TESTING MACHINE

(By courtesy of The British Standards Institution)

impact testing machine of the type illustrated in Figs. 5 and 6, the blow being applied in the tangential direction.

The Standard Specifications for the materials used in aircraft construction are subject to periodical review and possible amendment in order to keep abreast of progress. In this work, therefore, only typical examples of the tests laid down in such Specifications are given in order to assist the ground engineer to understand the function of the tests called for, and to realize more fully his exact duties when dealing with release notes and test reports.

Should there be any reason to doubt the condition of the timber during production of the finished parts, even though it has been previously approved, further check tests should be carried out.

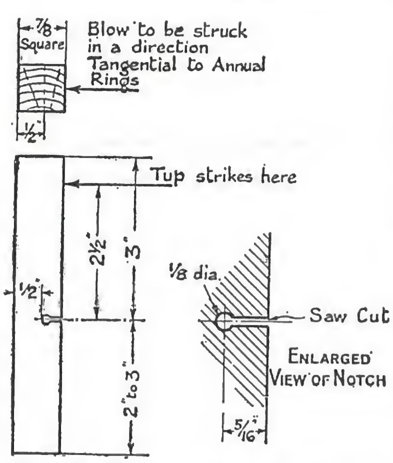


FIG. 7. STANDARD TEST PIECE

Spruce

This timber, which is used for the chief structural members of a composite aircraft, is known as Sitka spruce, a large percentage of which comes from British Columbia.

It is imperative to watch that the timber is free from dote and any form of decay, shakes, deleterious knots, and resin pockets. The timber must, further, be straight in grain and fibre. Dote is a disease which, when present in spruce, renders the timber very definitely useless for aircraft purposes. The inspector will have no doubt in rejecting timber if the dote is in the advanced stages of development, owing to the obviously decayed nature of the parts affected. The symptoms of dote in its early stages are detected in the form of yellowish or brownish spots which, however small, or indicating the slightest evidence of the disease, should cause the rejection of the member or members concerned, because the decay, once present, will spread.

The angle of cross-grain is determined by measuring the slope of the annual rings against the major axis of the piece of timber, and should not depart from the major axis by more than an inclination of 1 in 15.

The detection of spiral grain in finished spruce sometimes presents greater difficulty however. This defect is an inclination of the fibre of the annual rings, and if present is detected by examining the flower side or figured surface of a piece of timber. A more reliable check is to remove a short piece from the strut or member concerned, and split it with a chisel at right angles to the annual rings. It

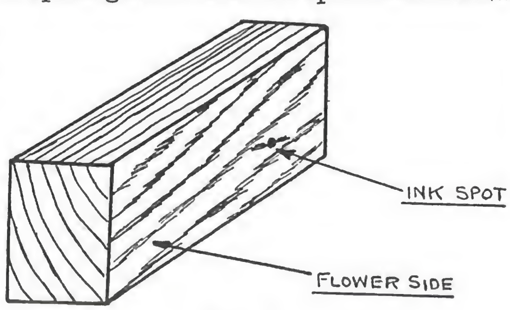


FIG. 8

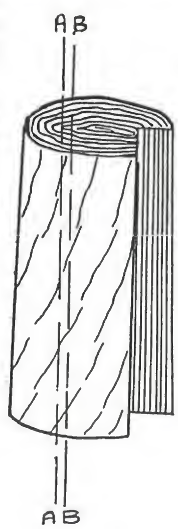


FIG. 9

may happen that such a specimen is not available; then detection must be made on the flower side of the timber by examination of the slope of the sap ducts. If it is impossible to discern the run of these sap ducts, a spot

FIG. 10

of ink will facilitate the detection, because if applied to the flower side of the timber it will run in the true direction of the grain. (Fig. 8.)

Many telegraph poles display very clear illustrations of spiral grain. On the surfaces of these poles it will be noticed that the very evident shakes lie in more or less spiral directions. In Fig. 9, showing a short length of a pole, is indicated the travel of the spiral grain, while the cross-section shows the straight travel of the edge grain. While this feature may not impair the strength of a pole if left uncut, the result would be

very obvious in a plank $AA - BB$ cut from the pole. The maximum limit for spiral grain is also 1 in 15.

Spruce containing resin pockets, unless they are very small compared with the section of the member, should be rejected, as the percentage strength reduction is unknown, and may render the member weaker than the design requirements. Acceptance may be considered at the discretion of the inspector, if they occur at or near to the neutral axis of the member.

Although the presence of resin pockets may be betrayed by local irregularity in the grain, the greater dimension of a pocket is often hidden. It

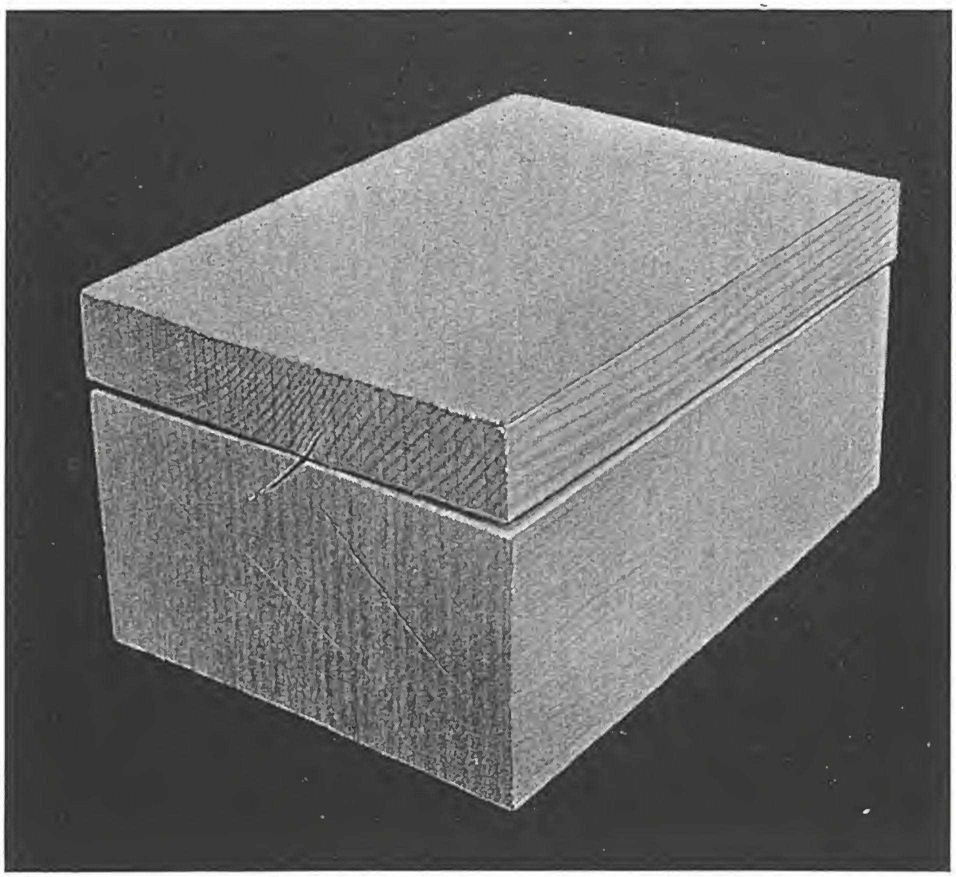


FIG. 10A

is imperative to explore the extent of a pocket before considering its acceptance.

Figure 10A shows a spruce specimen exhibiting the conditions mentioned, where further investigation has revealed the large pocket approximately 7 in. long, shown in Fig. 10B.

The danger of such hidden defects is not so great in modern design, however, since spars and struts are generally built up of comparatively thin laminations glued together. Since each lamination may be examined before gluing, there is every chance of detection of resin pockets and similar defects which are deleterious. Furthermore, hidden defects in thin laminations are less likely to cause serious diminution in the strength of the built-up member.

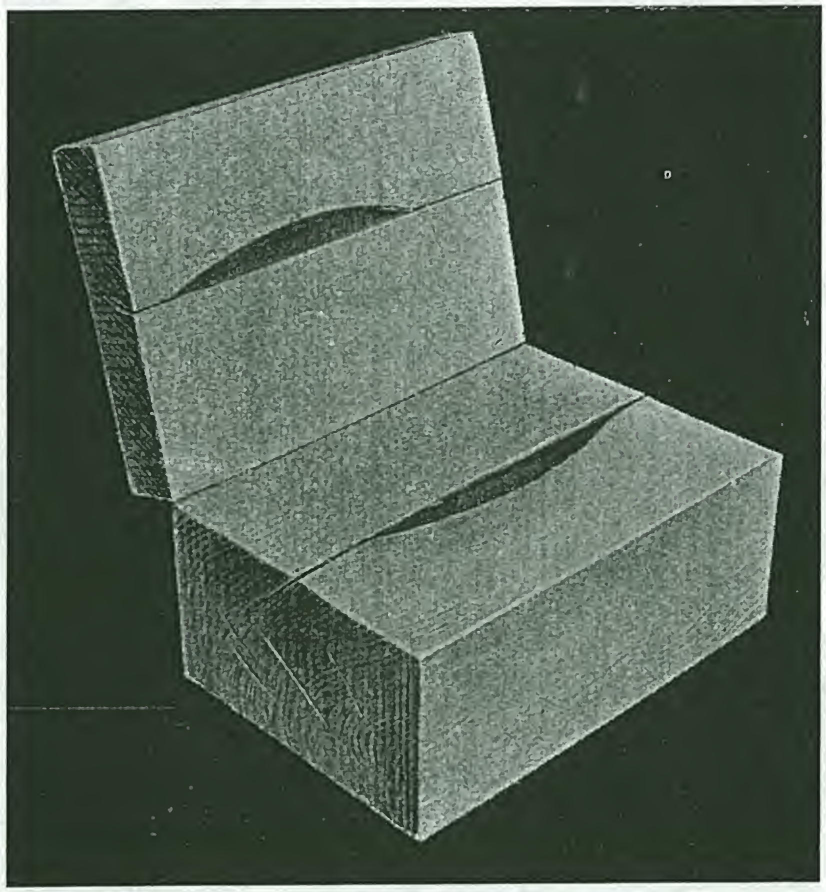


FIG. 10B

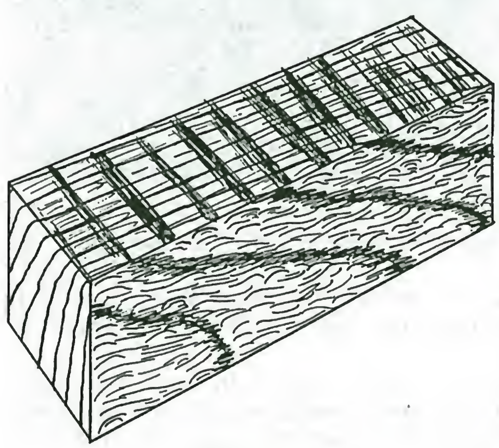


FIG. 11

Although it has been stated that resin pockets may be accepted in certain circumstances, spruce with resin veins should always be rejected, as these cause poor adhesion between the annual rings, with consequent risk of splitting down the grain.

A resin vein, as distinct from a pocket, runs with the grain in the form of a streak embracing one or more annual rings, and can be detected by discoloration.

Compression and felling shakes are detected by an apparent rupture of the edge grain in the part affected. (Fig. 10.)

The annual rings should not be less than 18 in any 3 in., while spruce with an excessive number of annual rings is often timber of low density.

It is important that spruce members, when finally shaped, should be adequately protected with an approved varnish, and in view of the timber being prone to gain or lose moisture, it should be protected as soon as possible after final shaping; varnishing should be carried out in a warm dry shop. The ends of wooden spars should be heavily coated with several applications of shellac or other approved material.

Ash

This timber should be cut from butt lengths of British-grown ash, which for preference has been felled between the months of November and March. It must be free from deleterious knots and shakes, and shall not contain any rammy or caney grain, nor show any signs of rot or decay.

Rammy or caney grain is illustrated in Fig. 11. Caney grain is just what its name implies, and is fairly clearly indicated on the end of the wood, which appears very porous. Ash with any of the above defects is useless, and should be rejected.

The annual rings of an ideal and strong ash are about four to the inch. The inclination of the grain to the length of the part being made must not exceed 1 in 10.

Ash is often required to be steam-heated for the purpose of bending. Care should be taken that the maximum temperature during steam-heating does not exceed 220° F. (2 lb. per sq. in.), and that the timber shall not remain under this heat any longer than is absolutely necessary, consistent with pliability. Parts made from this timber should be protected by an approved varnish as soon as possible after completion.

Walnut

The kind of timber used under this heading is almost exclusively American black walnut. It is mainly adopted for use in the manufacture of airscrews and for packing blocks. It is a very hard wood, and distinctly dark in colour, so that its identification is an easy matter to anyone with slight experience. The method of testing is similar to that already described for spruce, and the minimum results of such tests are mentioned in Table I, page 2.

This timber must not be reduced to its finished shape until the moisture content has been reduced to 13 per cent or less. Examination should be made periodically during conversion for deleterious knots, shakes, rammy figure, caney grain, rot, etc. The defects of rammy figure and caney grain have been described under the heading of "Ash," while the detection of the other defects will not be a matter of great difficulty to an inspector guided by experience.

Sapwood is not prohibited, providing it is sound, tough, and strong. Natural or artificial seasoning is permitted, providing authority is given for the particular method adopted. The maximum cross grain permitted is 1 in 12.

It is not possible, in the early stages of manufacture, to treat this material with a protective coating, but as soon as possible after its completion it should be varnished in order to avoid warping and variation in moisture content due to atmospheric conditions.

Mahogany

Honduras mahogany, which is obtained from Central America, is the timber most extensively employed in the manufacture of airscrews, and owing to its exceptional suitability for this purpose it has never met with much competition, although there are other varieties of this or like timbers

which might be equally suitable. It is also employed for the veneers of certain plywoods, and for packing blocks. The identification of the different kinds of mahogany by visual examination is no light task even for the expert, and the fact that often the same kinds of this wood vary considerably in colour renders distinction a job for one with considerable experience. Cedars have even been selected for mahoganies by mistake.

The properties required of an approved mahogany are shown in Table I, page 2, while the methods of obtaining the test results are as laid down at the beginning of this chapter.

Conversion to the finished shape must not be completed while the moisture content is above 14 per cent. The timber should be examined at definite intervals during conversion to the finished product for such

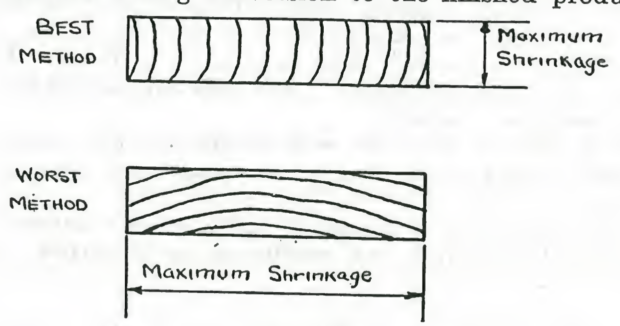


FIG. 12

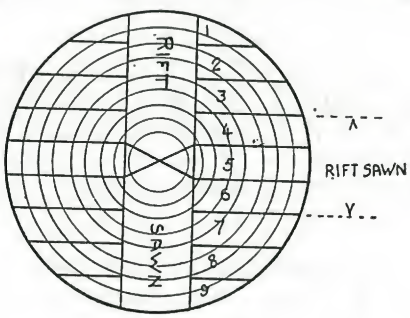


FIG. 13

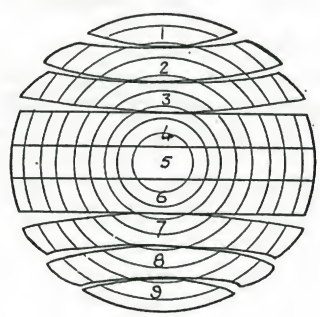


FIG. 14

defects as wormholes, gum veins, various forms of rot, knots, shakes, fiddle-back figure, cross and curly grain. Sapwood is not permitted. Both natural and artificial seasoning are approved for use, but the exact method should be individually authorized. The average inclination of the grain must not exceed 1 in 12. A protective coating should be added to the finished product as early as practicable, as it prevents any change in the moisture content and thereby minimizes the chances of warping.

Conversion of Timber

Rift-sawn timber (see Fig. 12) is ideal for all purposes, but cannot generally be enforced. The components of built-up details, such as box spars, should, however, be as nearly as possible rift-sawn, or at least with the angle of the annual rings not less than 45° with the broad surface of the section. Deep I-section solid spars are also cut to the best advantage in the same manner.

The principal advantage of rift-sawn timber in the construction of aircraft details is that it compensates for shrinkage. The ratio of shrinkage

in most timbers is greater in a tangential than a radial direction, therefore in the end section of a rectangular piece of timber the greater dimension should be radial, as is indicated in Fig. 13.

As already mentioned, the above is ideal, but cannot always be carried out economically, for instance, in the construction of airscrews; but if the principle is understood, a good deal can be done in the matching up of the various laminae.

With the above end in view, a popular method of cutting a log to produce as much rift-sawn timber as possible is illustrated in Fig. 13. This is, of course, a compromise, but it has been found an economical method of conversion, and produces timber of moderate width. It is generally found that the centre of the log, marked ×, is defective.

If a log is flat sawn as in Fig. 14, the outer planks 1, 2, 3, 7, 8, 9, will warp as they dry, the side nearest the heart becoming convex. This is more pronounced in the hard woods, but the same principle applies more or less to all timbers. The centre planks 4, 5, and 6 will remain flat when seasoned.

PLYWOOD

This material is usually constructed of three veneers of wood glued together while under pressure. The grain of the outer plies runs longitudinally with the length of the board, while the grain of the middle ply is at right angles to that of the outer plies, or across the board.

Where more than three plies are used, the material is termed "multi-ply." For the outer faces of three-ply, birch, mahogany, and teak are used, the latter always being employed together with a "soft core" or middle ply. Birch is used for the middle ply of "hard core" material, while such timbers as basswood, mahogany, and poplar form the centres of "soft core" plywood. Combining the veneers in this manner produces a very strong material.

There are various qualities, or grades, of plywood, but for the purpose of general description they may be divided into two main classes, the first being plywoods which are employed on structurally important parts of aircraft, such as fuselage sides and in spar construction, and the other class, which is used for unstressed or only lightly stressed parts, such as fairings.

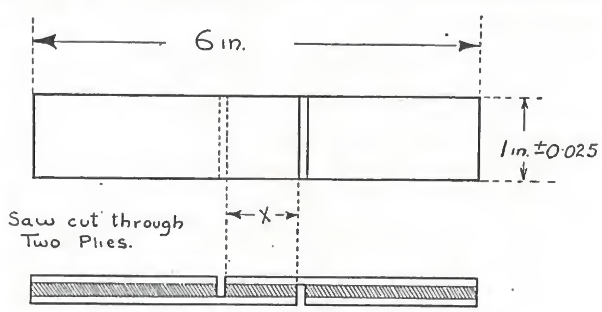


FIG. 15

X = 1 in. or 8 times the thickness of board, whichever is the smaller

The first of these classes is tested for the adhesion of plies, resistance to water, resistance to dry heat, and for moisture content, while the quality and thickness of the timber plies, and the direction of grain, also demand attention. The adhesive strength should not be less than 200 lb. per sq. in. of glued surface when a specimen prepared as shown in Fig. 15 is tensile tested. Further, when the veneers of the board are forcibly separated appreciable resistance should be offered to separation and the fractured surfaces must show adherent fibres of the wood distributed over the glued surfaces.

The plywood is tested for resistance to water by immersing two samples in boiling water for three hours, during which period no appreciable signs of separation of the plies should be evident. On the completion of this test, one of the specimens is plunged immediately into cold water, and after cooling, and while still wet, tensile tested in the manner described above, showing an adhesive strength of not less than 100 lb. per sq. in. of the glued surface.

The method of determining the resistance to dry heat is that of drying selected specimens for three hours in an oven at a temperature of 100° C. to 105° C. and allowing the specimens to cool to room temperature, when

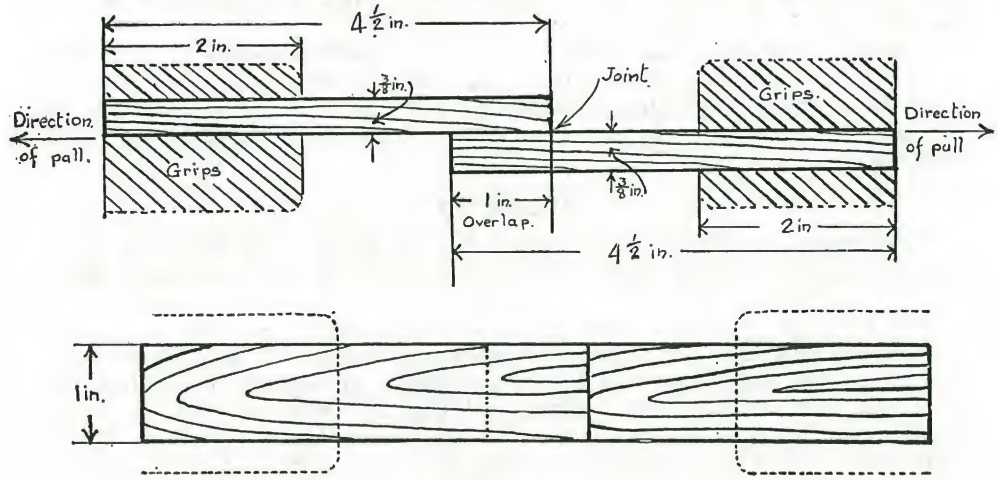


FIG. 16

the plywood should show no appreciable signs of separation or of the formation of blisters. The moisture content should lie between 8 per cent and 18 per cent, when a specimen about 2 in. square is checked in the manner described for spruce, with the exception that in this case the specimen is not dissected for the purpose of testing.

Multi-ply is also subjected to the above tests, except that a compression test is substituted for the tensile test.

For the unstressed class of plywood the adhesive strength test is omitted and greater latitude is allowed with regard to the kinds of timber used in the structure of the boards. Every care should be taken in the storage of plywood: that it is properly stacked and suitably housed. As there are different grades of this material, a very important factor is that the grades are kept entirely separate, and identified so that there is no possible chance of an inferior grade being used in the place of a higher grade plywood.

GLUES

These are of two kinds. The glues which are either in the form of cake or jelly, and which have to be redissolved in water, the cake variety being heated while the jellies are warmed before application, are in one category. The casein cements, or "cold" glues, are of the other kind, and possess a marked advantage over the "hot" glues, as they only require the addition of cold water in correct proportion to make them ready for use.

The method of testing is as follows: Two pieces of wood, preferably of American black walnut, each one inch wide, are glued together with the glue under test. A joint is formed by making a 1 in. overlap of the two pieces; thus the joint is one square inch in area (see Fig. 16). When

tensile tested this joint should stand at least 1,100 lb. per square inch. A similar specimen, after remaining in water for three hours, and drying under normal conditions for half an hour, should stand a pull of at least 1,000 lb. per square inch.

In carrying out this mechanical test it is assumed that the glue has already been tested for melting point, time of setting, etc.

Gluing

The process of gluing, because of its apparent simplicity, is rather prone to be treated carelessly, whereas, for aircraft work, it is highly important.

The rules on the makers' "Card of Instructions" should be strictly adhered to. In application the glued parts should be first clamped in the centre, with additional clamps placed in either side, working outwards to the ends of the parts. The joints should remain under pressure for at least 24 hours.

Where cake glue is being applied, the room should be free from draughts and maintained at a temperature of 70° F. That inferior results will be obtained as a result of the glue being chilled at any stage during the process of gluing is fairly obvious.

In the case of casein cements, which are prepared only with the addition of cold water, the relative amounts of water and cement prescribed by the manufacturer should be used.

The containers in which casein cements are supplied should be shaken before use to thoroughly mix the different ingredients, which may have become segregated to a greater or lesser degree during transit from the makers.

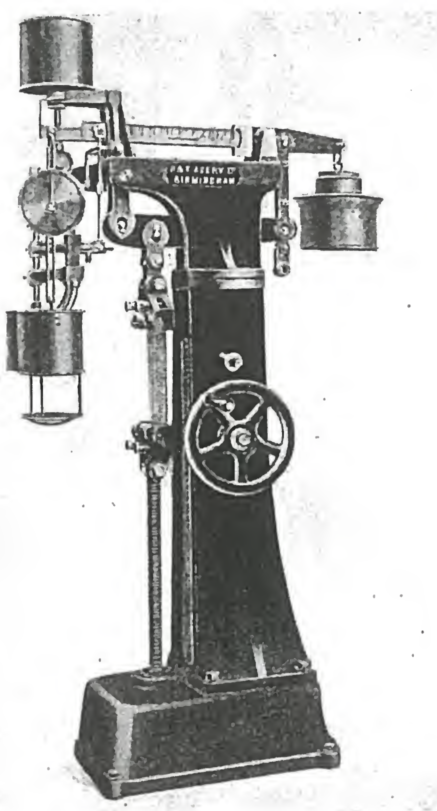


Fig. 17

FABRIC

For covering aircraft components, linen fabric is used, the weight of which is less than 4 oz. per square yard, with a breaking strength of not less than 90 lb. per square inch width of warp or weft when tested in the following manner.

The method of tensile-testing linen fabric is that known as the "wet method," in which the specimens to be tested are soaked in water for half an hour, then removed, and the excess adherent water removed before testing.

The object of "wet" testing is to ensure uniformity of testing conditions, because, if the fabric is tested "dry," the relative humidity of the

atmosphere may so perceptibly affect the results of the tests as to make them unreliable.

Fig. 17 shows a fabric-testing machine with a specimen under test.

A lighter fabric is used, of course, for glider work.

The testing of fabric to determine absolute conformity with the appropriate specification is to a certain degree of a specialized form, but the ground engineer should himself be able to carry out certain of the checks and tests, or supervise the operations when done by others, as necessity arises.

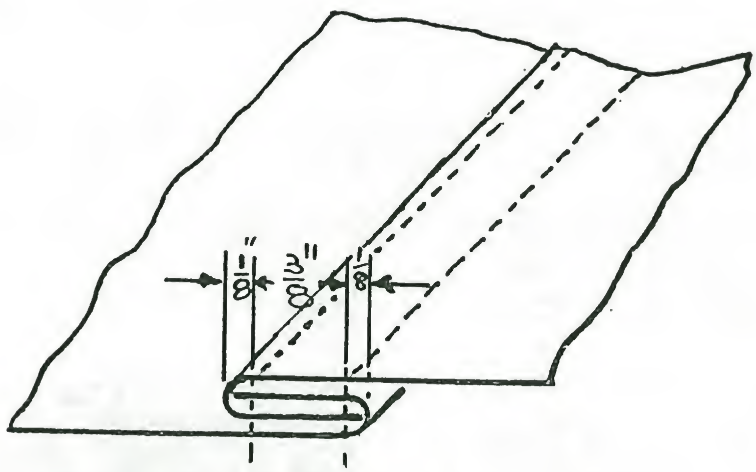


Fig. 18. Section of Seam for Sewing Lengths of Fabric Together

Such instances occur when there is doubt regarding the correlation of a piece of fabric to a certain approved release note, or if the fabric is suspect due to age or indifferent storage conditions. Among the checks possible are the following—

1. Count for ends and picks.
2. Width measurement.
3. Determination of weight per square yard.
4. Testing for strength.
5. Testing for weaving defects, such as snarles, floats, snubs, thin places, etc.

The exact nomenclature in weaving defects is not of prime importance when applying the fabric to the component, but it is important that fabric containing defects which would be detrimental so far as strength and durability are concerned is rejected.

Fabric Covering

Before any attempt is made to cover a component with fabric, a final inspection should be made to see that all the constructional work has been carried out satisfactorily. The fabric should be kept at as near the dope room atmospheric conditions as possible, and under no circumstances left to become damp. The covering, also, should be carried out in a shop which is well suited to the work.

Next, any parts likely to chafe or cut the covering fabric should be locally bound with tape. This binding should be reduced to a minimum, as it absorbs moisture, which is conducive to rotting the timber parts, or corroding the parts of an all-metal component.

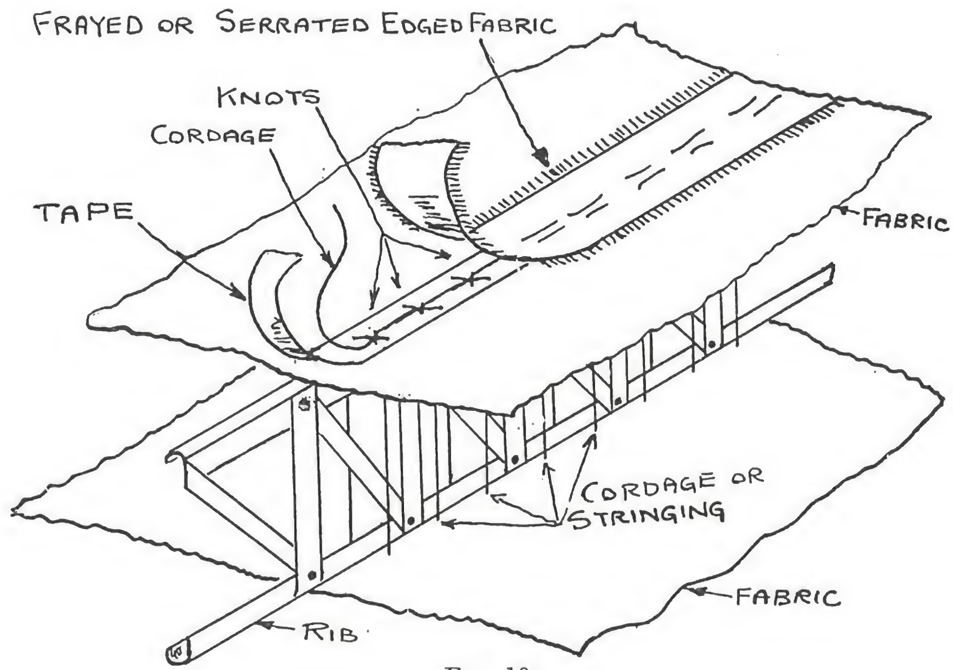


FIG. 19

On wooden components it is usual to glue to the top and bottom of the ribs, which would otherwise make contact with the covering fabric, a layer of Egyptian tape. All "contact" wood parts must have a coat of dope-resisting paint before fabric covering. Metal components should be adequately protected by stove-enamelling or other suitable coating, and it is unnecessary to apply tape to the ribs.

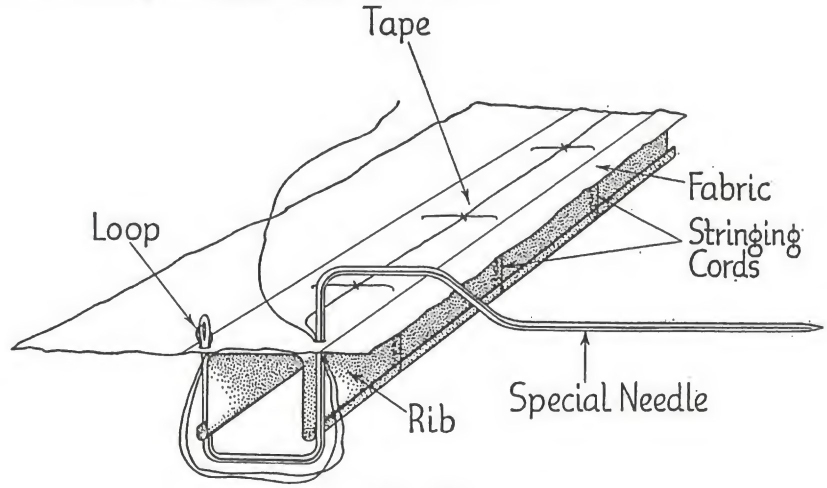


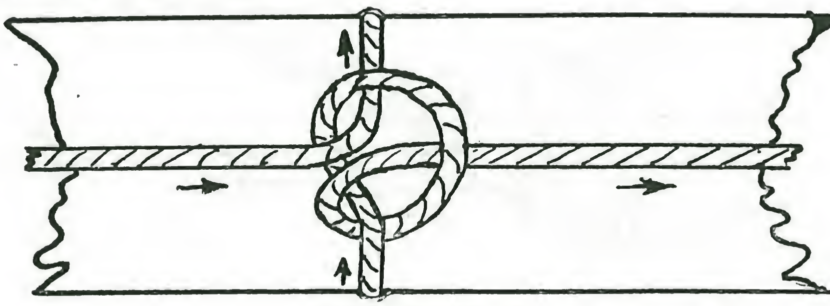
FIG. 19A

The covering fabric is placed on the component with the warp running in a fore-and-aft direction. Occasionally, design calls for the warp to run diagonally across the component. Previous to the application, and if necessary to provide sufficient width athwartships, the lengths of fabric are joined together in the manner shown in Fig. 18, which is known as the

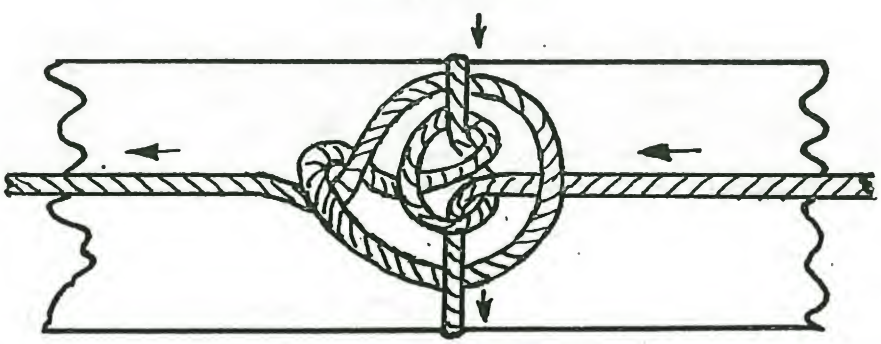
"double balloon seam." With this type of seam, it is important that each of the two rows of sewing passes through each of the four layers of fabric, and this may be checked by means of a light-box.

A light-box has a glass top, and inside is a powerful lamp, so that by passing the seam over the glass top it can be seen whether the sewing is satisfactory or not, because, while so passing, it can be seen through sufficiently.

The fabric is folded over the leading edge of the component, and joined up over the trailing edge. Here, after folding the fabric edges in, they are joined by sewing eight lock-stitches per inch, and double lock-stitching at every 6 in. The stitching thread should be either single 18s or double 40s linen thread to B.S. Specification F.34.



Single Knotting



Double Knotting

Fig. 20

During stitching, the fabric should be pulled taut over the component, but not so taut as to bend any members or to twist the component during the doping operation.

The stringing operation is next carried out. This consists of securing the fabric to the framework of the component by means of an approved cordage, in between which and the fabric is interposed a layer of tape as shown in Fig. 19. The cordage is only knotted on the top of the component. The pitch of the knots should be 3 in. where the cord is single knotted (see Fig. 20), and additionally double-knotted at approximately every 18 in. This pitch of 3 in. is reduced to $1\frac{1}{2}$ in. in the case of portions of the component which come in the slipstream of the airscrew when the engine is over 400 h.p. Over this stringing is doped a frayed or serrated edged tape as shown in Fig. 19.

With certain designs of fabric-covered components, especially those of a very deep section, or where the stringing would be fouled by control

wires or rods, it is impossible to use the straight-through stringing passing through the fabric on both sides of the component, as in Fig. 19.

In such cases the cord is passed round the rib boom and knotted externally in the usual manner, for which purpose a C-shaped needle is used.

If the boom section is too large, or of such shape as to render the use of a C-needle impossible, a special needle is used in the following manner—

After forming holes by piercing with the pointed end of the needle, the stringing cord is passed (with the needle eye first) through the tape and fabric on one side of the rib boom, round the rib boom, and out through the fabric and tape on the other side to the position shown in Fig. 19A.

The cord loop at the eye end of the needle is retained for the purposes of knotting, and the needle is withdrawn by sliding the eye over the single cord. The needle is then used for forming the knot, therein utilizing the loop on the other side.

During the process of doping, ripping panels and celluloid windows are added, and the draining holes cut.

After the drying period the component should be inspected to ensure that it is adequately doped in all respects and that no distortion of the component has taken place.

DOPES

For the purpose of tightening, strengthening, and protecting the fabric on aircraft components, dope is applied.

The dopes now used are pigmented, and are either acetate dopes or nitro-dopes. The basis of the former is cellulose acetate, while that of the latter is nitro-cellulose. The question of testing dopes for compliance with the specification is beyond the scope of this work and the work of a ground engineer, and there are no short or abbreviated tests which can be carried out beyond those of the practical application of the dope to fabric, and a careful examination of results. Only approved doping schemes should be employed.

Doping

This process may be carried out under either of two schemes, "Normal" doping or "Anti-chill" doping. Different types of dope are used in the two cases, but whatever scheme is adopted, every attention should be paid to the instructions of the manufacturer of the particular dope in use. The identification symbols of the doping scheme should always be painted on the components.

"Normal" dopes should be applied in a room free from draughts, at a temperature generally not below 70° F., and a relative humidity not exceeding 70 per cent. A suitable hygrometer must be provided to check these conditions.

Although draughts, in the ordinary sense, are to be avoided, the room should be regularly and suitably ventilated with motor-driven fans while doping is proceeding, otherwise the health of the workers may be seriously impaired. Regarding dope-room conditions, there are certain Home Office regulations which must always be observed.

The times for drying, and the methods of applying the dope should be strictly adhered to. The undoped covered component should be placed in the dope-room for a reasonable time before doping is commenced, and in any circumstances doping should not be commenced until the fabric is in a condition consistent with the atmosphere of the dope room.

"Anti-chill" doping schemes were really developed to meet emergency and adverse conditions where there is no alternative to doping at low temperatures and at high humidities, say, at 40° F. and 80 per cent

humidity. Instances of such cases occur where there is no dope-room available, or when, owing to the large proportions of certain aeroplane components, it is impossible to accommodate them in the dope-room. Even under these circumstances the best available housing should be sought, and doping should not proceed until the atmospheric conditions are within the limits laid down for the particular scheme.

Whatever doping scheme is adopted, it is essential to keep the dope well stirred to ensure thorough mixing; and immediately before pouring from the dope drum to the smaller cans, for shop use, the dope in the drum should be thoroughly shaken or stirred.

The doped component must be finally inspected for—

1. Weight of dope.
2. Uniformity of doping.
3. Smoothness of surface.
4. Uniformity of colour.

The average weight of dope applied should be between 2·5 and 3·5 oz. per square yard.

PAINTS AND VARNISHES

Any material under this heading must always be definitely approved and released to either a B.S. or D.T.D. specification, because the average commercial paint or varnish is unsatisfactory for coating aircraft parts.

The following are among the specifications in general use for protectives for woodwork—

B.S. Specification 3.X.7	Varnish for internal woodwork
B.S. Specification 2.X.17	Seaplane varnish
D.T.D. Specification 62A	Pigmented oil varnish
D.T.D. Specification 63	Cellulose enamel

while the following are in general use for metal parts—

D.T.D. Specification 56A	Stoving enamel
D.T.D. Specification 62A	Pigmented oil varnish
D.T.D. Specification 63	Cellulose enamel

Beyond the familiar everyday rulings regarding the actual application of these materials, there is little to say. It is essential, however, that the parts, before being brushed or sprayed with the protective coating, should be perfectly dry and free from rust. Rust, even though covered with protective coating, will extend and, in the majority of cases, cause the enamel to flake or peel off.

RUBBER HOSE

Rubber tubing which is suitable for the conveyance of aviation fuel may be in either of two classes. The ordinary class is made of an inner

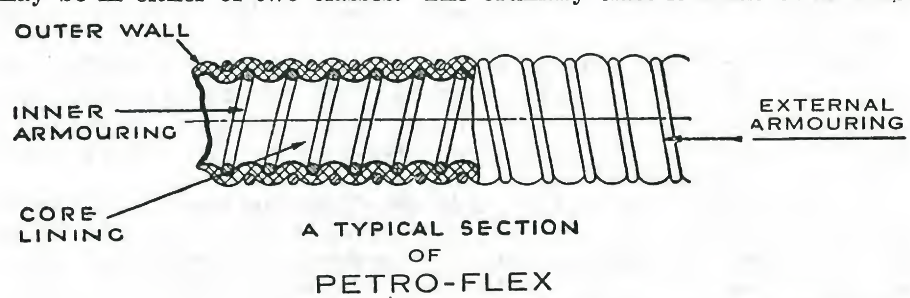


FIG. 21 *(By courtesy of Smith's Aircraft Instruments)*

lining of rubber covered with a number of plies of cotton canvas, which in turn is covered with an outer covering of rubber, the whole being vulcanized together. The other, known as the armoured class, is similar to

the above, but is reinforced by a helix of high tensile steel wire, embedded in the wall of the tubing between two plies of fabric. This tubing is supplied only to definite lengths, as 3 in.; each end is left unarmoured for the purpose of accommodating fixing clips.

The strength of the canvas and quality of the rubber are checked before fabrication into tubing. The amount of free sulphur in the vulcanized rubber compound (excluding the canvas) should not exceed 2 per cent by weight.

To test for permeability to aviation fuel, a sample of the hose 14 in. long is plugged at one end. At the other end is fitted a glass tube 18 in. long, leaving 12 in. of rubber hose between the plug and the glass. It is then filled with fuel to D.T.D. 224 to a level 12 in. above the bottom of

FIG. 22

the glass tube. The glass tube is closed with a cork. By frequent additions the loss of fuel is made good, so that the level never falls more than 3 in. during the first 48 hours. The room temperature should be between 60° and 70° F. The loss of fuel during the third 24 hours shall not exceed 200 milli-litres per sq. ft. of the original internal surface of the hose.

The tubing is tested for resistance to benzol by boiling a 3 in. length for 1 hour in benzol, using a reflux condenser. The apparatus is then allowed to cool down and stand for 24 hours. After removal, $\frac{1}{2}$ in. lengths are cut from each end, and the remaining 2 in. examined. The rubber should show no tendency to separate from the canvas, and should not be friable, i.e. in such a condition that it can readily be disintegrated. The area of the bore when checked by rod gauges shall not differ from the original area by more than 25 per cent for hose above $\frac{1}{4}$ in. internal diameter, or by more than 35 per cent if the internal diameter is $\frac{1}{4}$ in. or less.

The construction of rubber hose for use with hot water is similar to that for use with aviation fuel, but the tests are not so rigorous. The free sulphur of the vulcanized rubber compound (excluding the canvas) should not exceed 1 per cent by weight.

Proprietary brands of flexible tubing have to a large extent displaced the ordinary rubber hose. Such flexible tubing as "Petroflex," "Superflexit," "Titeflux," and "Avioflexus" are among these brands.

"*Petroflex*," which resists the action of petrol, benzol, and all the hydro-carbon oils, is built up of two walls reinforced internally and externally with coiled wire. Fig. 21 shows the general method of construction. This tubing must not be used for conveying water or steam.

The inner wall or lining, which carries the fluid, consists of a number of layers of natural product specially treated and cemented, and is fitted in tubular form in order to avoid lateral and transverse joints.

The layers of the inner wall vary in number in accordance with the pressure and work to which the tubing is to be applied. The outer wall comprises a specially woven, treated and proofed canvas which is fitted longitudinally, thus eliminating transverse joints.

The internal armouring is practically embedded in the core lining, while the outer wire, although fitting snugly, is proud of the outer casing.

"*Superflexit,*" which is impervious to petrol, oil, water, etc., is a reinforced tubing constructed in the following manner—

A tube of cellulose is built on to an inner wire helix so that it lies between the convolutions of the wire and forms the inner lining for conveyance of the liquid. Over this and in turn are appropriately bound fabric strip, sheet rubber, and cotton duck, the latter being proofed to resist petrol and oil. Finally, a wire helix reinforcement is suitably applied to the outside.

"*Titeflex,*" which is approved for use on aircraft, consists of a profiled non-ferrous metallic strip spirally wound into a convoluted tube. A double-locked fixed seam is rolled under heavy pressure at the top of each convolution.

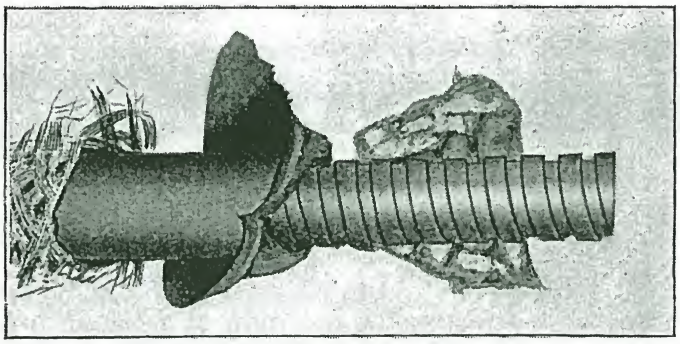


FIG. 22A

This tubing is covered on the outside with two layers of woven casing consisting of fine-gauge tinned wire, the number of strands per plait varying with the size tube. This casing serves to prevent any elongation and twisting under pressure, and as a protection for the tube itself against excessive bending or twisting and general abuse in handling.

The end connections, which are of brass, are soft-soldered to the tube. In the soldering operation it is important that the flux used is non-corrosive. In applying and soldering the end couplings to "Titeflex" metal hose, the makers' instructions and any standard ruling should be strictly observed.

Fig. 22 will give the reader an idea of the method of construction and attachment of the end fittings.

The tube is tested with the end couplings completely fitted, and when bent to the minimum radius laid down for the particular diameter of tube, it shall show no signs of leakage when submerged in water and subjected to an internal air pressure of 100 lb. per square inch.

It should be understood that the test pressure of 100 lb. per square inch mentioned above is normally adopted as being sufficient to cover all normal requirements, but pressures up to 2,000 lb. per square inch have been withstood by this class of tubing.

NOTE: Titeflex is entirely metallic, but has been added to this section as it falls under the heading of flexible tubing.

"*Avioflexus*" *Tubing* is applied to both aircraft fuel and oil systems. It is built up from an inner flexible tube of aluminium or brass, according to requirements, directly covered with cellulosic sheet which is bound with twine between the corrugations. Superimposed upon this cellulosic covering is a rubber tube which is vulcanized in position. The whole is then protected and reinforced by a strong braiding consisting of tinned iron wire. See Fig. 22A.

After the end connections have been fitted, each length of tubing is filled with paraffin and subjected to pressure for at least one hour, during which period there should be no evidence of leakage or failure. For tubes not exceeding $\frac{3}{4}$ in. diameter bore, 100 lb. per sq. in. pressure is applied, and for tubes of greater diameter, 75 lb. per sq. inch.

These types of tubing are all fitted with special designs of end fittings forming the connecting unions, which also provide a means of electrically bonding each tube from end to end. The tubing is tested for pressure, flexibility, permeability, and resistance to heat, the tests varying to some extent in accordance with the class in which the type of tubing falls.

The tubes are usually supplied by the makers to the lengths ordered, and with the end fittings properly attached, but should it become necessary to change or detach the end fittings, the particular instructions laid down regarding the method of attachment of these fittings should be strictly adhered to, as indifferent fitting will lead to the possibility of leakage.

RUBBER SHOCK ABSORBER CORDS

This cord consists of a multiple number of rubber threads which have been tightly bound in two layers of cotton braid while in a very outstretched condition. It is applied for taking the shock load in landing on certain types of aircraft, by being suitably connected on the undercarriage and on the tail skid.

As the useful life of rubber is comparatively short, and it is a matter of some difficulty to determine visually whether it should be replaced or not, it is important to know the approximate date of manufacture, and the specification allows for this by having specially coloured cottons interwoven with the braiding. The particular colours for each year are—

1933 . . .	Green	1937 . . .	White
1934 . . .	Heliotrope	1938 . . .	Green
1935 . . .	Yellow	1939 . . .	Heliotrope
1936 . . .	Blue		

and the number of cottons to be included are—

Cord made between—
- 1st January and 31st March inclusive 1
- 1st April and 30th June inclusive 2
- 1st July and 30th September inclusive 3
- 1st October and 31st December inclusive 4

The mechanical properties of the cords are given in Table II—

TABLE II

Size of Cord	Load in lb. to give 10 per cent Extension	Load in lb. to give 100 per cent Extension			Load in lb. in Addition to the Actual Load Producing 100 per cent Extension to give an Extension of 105 per cent of the Initial Length of the Finished Cord
		Finished Cord		With Outer Braiding Removed	
In.	Min.	Min.	Max.	Shall be not less than 45 per cent or more than 55 per cent of the actual load obtained on each finished cord	Max.
$\frac{3}{8}$	15	70	90		15
$\frac{1}{2}$	30	130	155		25
$\frac{5}{8}$	42	200	240		40

After removal of the loads in Table II, restitution shall be prompt and complete. There are certain variations in the above test results for different temperatures, and for these the particular specification makes graduated allowances.

LEATHER

The use of this material for anything beyond the manufacture of straps, etc., for fixing equipment, should be discouraged.

It should never be used under pipe clips or at all permanently in direct contact with structural metal parts, as it assists corrosion to a very marked degree. It may be used providing that some such material as "Langite" or "Systoflex" is placed between it and the metal.

CHAPTER II

METALLIC MATERIALS

THE metals under this heading which are used on aircraft are iron, steel, aluminium, including its alloys, such as duralumin, and the combination of duralumin and aluminium known as alclad; copper, and the various brasses and bronzes.

Iron

The almost exclusive uses of this metal, apart from its use in steel manufacture, are for welding and as a wire for locking purposes on turnbuckles, etc.

It is applied for the former purpose owing to its adaptability as a filling medium in welded joints. The essential point in its inspection is that it shall comply with the appropriate specification, which calls for a content of ·1 per cent of carbon, and for the absence of foaming and spluttering during welding.

Steel

This metal is used to many and varied specifications, but generally the steels may be classed under such main headings as mild, high tensile, stainless, and steels suitable for case-hardening.

The mild steels are low or medium in carbon content, with an ultimate tensile strength between 25 and 40 tons per square inch. Such steels are used in the form of bar, sheet, tube, and forgings or stampings.

Those of the high tensile variety are generally alloy steels, which possess such contents as nickel, chromium, tungsten, manganese, molybdenum, etc., with always a certain percentage of carbon. The range of tensile strengths, which varies with the proportion of the various elements and with the particular heat treatment applied, fall between 45 and 100 tons per square inch.

High tensile steels are used in the form of bar, sheet, strip and tube, castings, forgings, and stampings.

Stainless or Rustless Steels are alloy steels with a comparatively high percentage of chromium, which gives them the quality of being rustless. It might be pointed out at this stage that such steels will not entirely resist the intensive action of the chlorides of the sea and sea air, but they go a very long way towards this object. Although it is not always possible, the resistance to rust is assisted by keeping the steel clean and minimizing any prolonged action of corrosive deposits.

Mild Steel Sheet

In the manufacture of wiring plates and built-up fittings which have to be bent or welded, hot rolled mild steel to B.S. Specification 3.S.3. is extensively used. The chemical composition of this steel is as follows—

Carbon	·2 to ·25 per cent
Silicon not more than	·3 per cent
Manganese not more than	·6 per cent
Sulphur not more than	·05 per cent
Phosphorus not more than	·05 per cent

The sheets and strips after rolling are re-heated at a uniform temperature of not less than 500° C. and allowed to cool freely in still air.

The material should conform to the following mechanical tests—

(*a*) *Tensile Test*

0·1 per cent proof stress (all thicknesses)
Not less than 16 tons per sq. in.

Ultimate tensile stress (all thicknesses)
Not less than 28 tons per sq. in.

Elongation (for thicknesses greater than 12 S.W.G.)
Not less than 20 per cent.

For purposes of these tests, the tensile test samples are cut from sheets so that the longitudinal axis of the test piece is at right angles to the

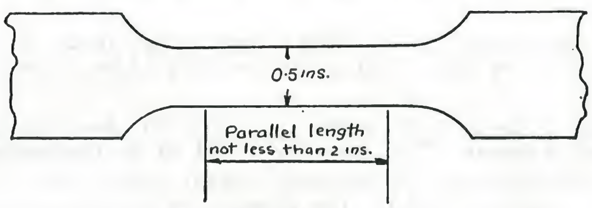


FIG. 23

direction of final rolling, and in the case of strip material parallel with the length of the strip.

The elongation is measured on a gauge length of 2 in. and a width of 0·5 in. (see Fig. 23).

(*b*) *Single-bend Test* (12 S.W.G. and thinner).

The test pieces must withstand, without cracking, being bent over a radius equal to half the nominal thickness of the sheet or strip.

(*c*) *Reverse-bend Test* (12 S.W.G. and thinner).

The test pieces are fixed in a vice between formers, the inner edges of which have a radius equal to three times the nominal thickness of the sheet or strip. The projecting length of the test piece is then bent at right angles to the fixed end, first to one side and then to the other, until the test piece breaks. Each test piece must withstand without cracking three bends through 180°, the first bend through 90° not being counted.

(*d*) Each sheet and strip shall be bent at the corner through 180° over a radius equal to half the nominal thickness of the material, without cracking.

Mild Steel Bars

A steel which is extensively employed in the manufacture of low tensile bolts and nuts is that complying with B.S. Specification 3.S.1. It has a chemical composition of—

Carbon between	0·15 and 0·40 per cent
Silicon not more than	0·30 per cent
Manganese between	0·50 and 0·90 per cent
Sulphur not more than	0·05 per cent
Phosphorus not more than . . .	0·05 per cent

The material should be free from the defects which are mentioned under "Defects" described in this section.

The margins of manufacture are tabulated in the specification, and the finished bars are delivered in the cold rolled, drawn, or machined condition.

At the option of the manufacturer, the bars may be reheated at a

temperature not exceeding 620° C. before or after cold working. The mechanical properties of the steel are as follows—

Maximum stress	between 35 and 45 tons per sq. in.
Elongation	not less than 15 per cent
Reduction of area	not less than 40 per cent
Izod value	not less than— 40 ft.-lb. for bars up to and including $\frac{3}{4}$ in. diameter (or width across flats) 25 ft.-lb. for bars over $\frac{3}{4}$ in. and up to $1\frac{1}{8}$ in. diameter (or width across flats) 20 ft.-lb. for bars over $1\frac{1}{8}$ in. diameter (or width across flats)

Steel Tubes

Apart from the chemical composition of steel tubes, the important factors in the acceptance of tubing are methods of manufacture, heat treatment, mechanical tests, freedom from defects, dimensions, and straightness.

Taking, for example, the tubing called for in B.S. Specification 2.T.1, the chemical composition of which is—

Carbon not more than	·4 per cent
Silicon ,, ,,	·35 ,,
Manganese ,, ,,	1·75 ,,
Sulphur ,, ,,	·05 ,,
Phosphorus ,, ,,	·05 ,,

Such tubing is extensively used in the formation of struts for the structural parts of all-metal aircraft. The tubes are seamless and cold drawn, which means that they are solid drawn to their finished dimensions without heating during the process of drawing. This cold working improves the tensile qualities of the material without impairing the other qualities. The tubes are then "blued" by being heated to a temperature between 350° C. and 480° C. and cooling in still air.

The defects for which steel tubes are examined are seams, draw marks or scores, which may be caused by scale or dirt between the tubes and the dies, and such defects as are sometimes found in bar steels.

The outside diameter and the gauge or thickness are the only dimensions required for the description of the cross-section of a tube unless that tube happens to be specially tapered, streamline in form, or otherwise differently shaped at various intervals in its length. This stated diameter is taken as the nominal diameter, and limits are tabulated in the specification for each size of tube. Likewise limits controlling the allowable variations from the mean thickness or gauge of the material are stated.

The observance of the ruling regarding these limits is imperative, as the tubing often has to be fitted by socketing, or used as liners in other parts or larger tubes of the aircraft structure, so that satisfactory functioning and efficiency of assemblies affected depend on this factor.

Tubes must always be free from kinks or any local bending, and in any selected length of 20 in. the bow must not exceed 1-600th of the length.

The maximum tensile stress of tubing to 2.T.1 Specification is not less than 35 tons per square inch. When the full section of the tube is used for this test, the stress values are calculated on the nominal thickness of the tube, but if a strip of the material is used the actual dimensions of the test piece are taken for calculating the stress.

The flattening or bending test is carried out by placing a ring of the material between flat faces as in Fig. 24, the faces being struck six to twelve times with a hammer until the distance between the faces is equal to three times the nominal thickness of the tube. This test must be withstood without any sign of cracking.

A proof bend test is carried out on each tube, being applied to alternate ends of the tubes of each batch heat-treated together. A special machine

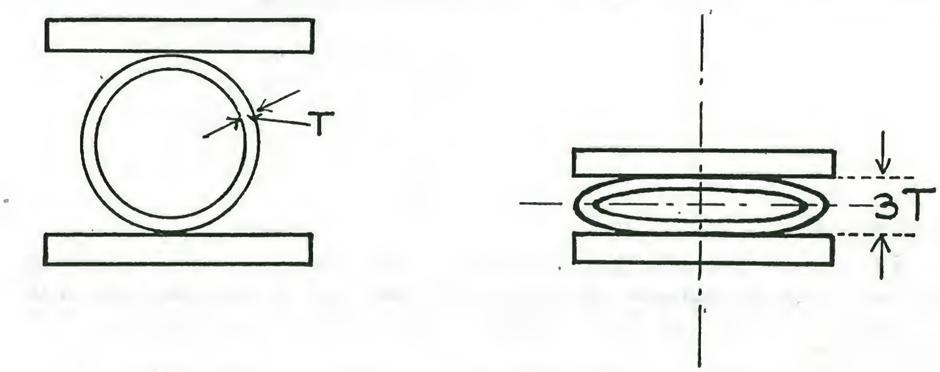


Fig. 24

is employed for this test, and is designed to avoid injuring the tubes. Fig. 25 shows diagrammatically how the load is applied. The tube is held down at A and supported at C while the proof load is applied at B. The deflection δ is measured at a predescribed point E.

Upon application of the load, the deflection registered should not exceed by more than 5 per cent the calculated deflection for a tube of

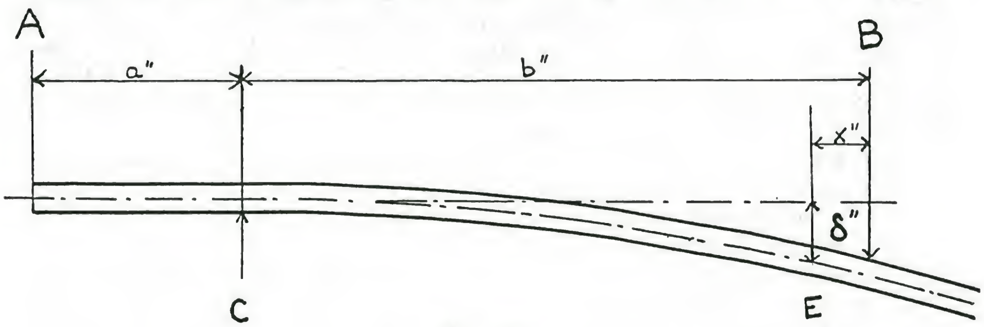


Fig. 25

similar dimensions and loading, by using a bending stress of 30 tons per square inch and a value for Young's Modulus of 13,300 tons per square inch.

The full details, with a complete description of the testing apparatus, are given in the specification.

Copper

Copper is used in its pure state in the form of tubing and of wire for electrical purposes. It is also used with other metallic elements to form such alloys as duralumin, brass, and bronze.

The chemical composition of copper tubes employed for petrol and oil systems and for general purposes on aircraft is copper not less than

99·2 per cent, arsenic between ·3 and ·5 per cent, while the impurities must not exceed ·05 per cent of antimony and ·01 per cent of bismuth.

The tubes are solid drawn, and must be free from defects. Tubes up to and including 1 in. outside diameter are supplied by the maker in the fully softened condition, which softening is carried out by heating uniformly to a temperature between 600° C. and 700° C. In this softened condition they may be worked for fitment in aircraft without further heating. Tubes of over 1 in. outside diameter are supplied in the half-hard condition, and are heated for bending and working, after which they should be carefully annealed at the above temperature. The special limits of diameter and thickness which are specified should be strictly adhered to.

The tubes are subjected to the following tests:

A *Tensile Test* is carried out on a flattened strip cut from the tube, and must give a maximum stress between 14 and 17 tons per square inch for the softened tube, and not more than 20 tons per square inch for the half-hard tubes.

The *Flattening Test* is carried out on a test piece not less than 2 in. long, and this must stand flattening until the interior surfaces meet without any evidence of cracking.

Drifting Test. Tubes up to and including $\frac{1}{2}$ in. outside diameter shall be expanded at the ends by drifting, to an angle of 30°, or until the outside diameter of the drifted end is not less than 50 per cent greater than the original diameter, while tubes above $\frac{1}{2}$ in. outside diameter shall be drifted until the outside diameter is not less than 25 per cent greater than the original diameter of the tube. In each of these cases there shall be no signs of cracking, otherwise the tube should be rejected.

Bore Test. Each tube shall be internally cleared by means of steam or compressed air. Tubes of less than $\frac{3}{8}$ in. outside diameter shall be tested by passing air at low pressure through the tube, and while the outlet end of the tube is immersed in water, shall emit a continuous flow of air. For tubes of $\frac{3}{8}$ in. diameter and over, a visual examination by the inspector is sufficient.

The Hydraulic Test. Every tube must be subjected to a hydraulic test pressure of 250 lb. per square inch without showing any signs of failure. High pressure copper tubing is subjected to a hydraulic pressure of 6,000 lb. per square inch, under which test there must be no signs of failure.

Flexible Steel Cable

The wire from which this cable is made is lower in phosphorus and sulphur contents than other aircraft steels, which, of course, increases its flexible property.

All wire is coated by hot galvanizing before being drawn to its final size, as a measure against corrosion. In addition, the wire for the manufacturing of straining cords is to be evenly tinned. Previously to being labelled as ready for the rope or cable manufacture, each length of the wire is tested in tension and torsion as laid down in the specification. The numbers of wires and strands employed in the various strengths of the cables are tabulated in the specification.

Each length of cable is checked for missing wires, slack strands, crossed wires, crossed strands, kinking, and other irregularities which will produce inefficiency in the cable.

Finally the cable is tested and inspected for diameter, weight, construction, uniformity of lay, and breaking strength. At the completion of these tests each cable must be wound in an approved manner on a reel

with a barrel having a diameter of not less than 30 times the diameter of the rope in the case of extra-flexible ropes, and not less than 40 times the diameter in the case of straining cords.

It is also imperative that each coil of rope bears a tally marked with the specification number, an identification mark, and an indication regarding the method of coating—that is, galvanized and tinned, or galvanized only—the test report number, and the stamp of the inspector.

Brasses and Bronzes

Brasses in the form of bar are employed in the manufacture of nuts, bolts, unions, nipples, etc., while elbows, three- and four-pieces for pipe connecting are made from brass castings. For certain bearings and parts requiring hard-wearing properties phosphor bronze and gunmetal are extensively employed.

Brass sheets are occasionally called for in the design of tank shells, but apart from this brass sheet is only used for such parts as securing clips and for lightly stressed work.

The chemical composition of brass bars suitable for brazing or silver-soldering is—

Copper between 78 and 82 per cent.
Total impurities not more than 1·25 per cent, of which lead must not exceed 1 per cent.
Zinc, the remainder.

The maximum tensile stress stated in the specification is not less than 20 tons per square inch. The tensile test piece for this and the brasses described in the following paragraphs has a gauge length of four times the square root of the sectional area of the specimen. A simple bend test is carried out by bending the specimen over a radius equal to the diameter of the specimen, through an angle of 120°, which test must be withstood without cracking. For bars over 1½ in. diameter, the bend specimen is turned eccentrically to the 1½ in. diameter, so that it includes the skin at one side of the bar, and the specimen bent with the skin side in tension.

For high speed screwing and turning, a brass bar of the following composition is used—

Copper, not less than 55 per cent.
Lead, between 1·5 and 3 per cent.
Total impurities, not more than 1·75 per cent.
Zinc, the remainder.

It has a tensile strength of not less than 25 tons. No bend test is called for.

High tensile brass consists of—

Copper, between 54 and 62 per cent.
Total metals other than copper and zinc, not more than 7 per cent.
Zinc, the remainder.

The maximum tensile stress is not less than 35 tons per square inch for bars under 1 in. diameter, and 30 tons per square inch for bars over 1½ in. diameter.

Referring generally to the above brasses, for the purposes of comparison, a Brinell test is carried out on a flat, filed on the tensile-tested bar, and then similarly on otherwise untested bars. It is possible, by comparing the hardness numbers with those obtained with the original bar, to decide that the material is homogeneous.

On all the above brasses, various methods of manufacture are permissible, including extruding, rolling, and drawing. The bars must be free from surface and other defects, such as piping. All bars approved are stamped with the specification number, the inspector's identification mark, and the manufacturer's trade-mark or symbol.

Phosphor-bronze is an alloy consisting of 10 to 13 per cent tin, ·5 to 1 per cent phosphorus, the remainder being copper, with an allowance of not more than ·50 per cent for total impurities.

MONEL METAL

This is a high Nickel Copper alloy from which is produced both sheets and bars. It is distinct in its resistance to all forms of corrosion. The Chemical composition is as follows—

Nickel not less than	64·0 per cent
Nickel not more than	70·0 per cent
Manganese not less than	0·3 per cent
Manganese not more than	2·0 per cent
Iron not more than	2·5 per cent
Total Impurities not more than	0·3 per cent
Copper	the remainder

It is delivered in the form of sheet in the annealed condition, with the following mechanical properties—

(*a*) Maximum stress—not less than 30 tons per square inch.

Note. The 0·1 per cent Proof Stress is not less than 7 tons/sq. in.

(*b*) Close Bend Test: The test pieces must withstand without cracking being bent through 180° and closed down flat.

(*c*) Bend Test on Sheets: The actual sheet is tested on one corner and must withstand without cracking being bent through 180° and closed down flat.

In Bar form in the annealed condition, and suitable for cold bending, the properties are as follows—

Maximum Stress not less than	30 tons/sq. in.
Elongation not less than	35 per cent

Brinell Tests. A Brinell test is carried out on 10 per cent of the bars in each parcel, and the hardness number compared with the Brinell test number of the Tensile specimen, in order to determine that the material of the whole consignment is homogeneous.

Bars in the rolled, drawn and tempered condition have the following properties—

0·1 per cent Proof Stress not less than	30 tons per square inch
Maximum Stress not less than	45 tons per square inch
Elongation not less than	18 per cent.

This material is also suitable for forgings and stampings.

INCONEL

The use of this alloy is steadily increasing in its application to aircraft. The reason for this is that it contains approximately 80 per cent nickel, 13 per cent chromium, and the remainder iron, and such an alloy as this has a high resistance to corrosion and heat oxidization.

It is hardened by cold working, and not by heating. By this method its strength can be increased from 36 tons per sq. in. to approximately 85 tons per sq. in. It may be soft-soldered, silver-soldered, brazed, or welded by the oxy-acetylene or metallic arc processes.

With its special properties, it is not surprising that its use is increasing

in the manufacture of exhaust pipes and manifolds and cabin heaters, where it is applied also in tubular form.

The mechanical properties are as follows—

	Tensile Strength	Yield-point	Elongation
	Tons/sq. in.	Tons/sq. in.	Per cent.
Sheet and Strip			
Annealed	35–40	13–15	45–55
Rod			
Annealed	35–40	13–15	45–55
Cold drawn	45–50	35–40	20–30
Wire			
Annealed	35–40	13–15	45–55
Spring temper	78–85	—	—

Inconel is annealed by heating to a temperature between 1,000° and 1,050° C., soaking for only 5 minutes at this temperature and allowing to cool in air. The rate of cooling is not important. The furnace should be electric, or one fired with gas or a high-grade oil. Coal or coke furnaces are unsuitable. The furnace should be brought to the required temperature before the articles are put in.

If formed parts are to be assembled by welding, it is desirable that after forming they should be annealed in the manner described above, before welding is commenced.

IDENTIFICATION OF MATERIALS

All aircraft materials must be properly tested, released, and correlated with their particular release notes, and the care and attention thus demanded would not have the desired result if, when any such material reached an aircraft maker or repairer, the correlation was immediately lost and its significance ignored.

In this connection it is absolutely imperative that when, say, a high tensile steel part is being fitted to an aircraft under any circumstances whatsoever, there shall exist satisfactory evidence that the fitting is made from material to the requisite specification, and that it is not by mistake made from mild steel having approximately half the strength required for the fitting. It is therefore essential that at all places where aircraft are manufactured or repaired, an adequately bonded stores should be maintained where materials may be kept for these specific purposes.

Only approved aircraft materials should be kept in this store, so that there is no possibility of non-aeronautical materials being mixed therewith, and in addition, only authorized personnel should be allowed access thereto.

All bars, tubes, sheets, castings, etc., should be marked or symbolized so as to identify them with the particular covering release note. In addition, if the stores contains large stocks of various aircraft materials, it is usual to employ a "colour scheme" which will facilitate identification of a material with the specification, and avoid the many possibilities of mixing the different materials after issue to the workshops. This "colour scheme" includes painting each bar, tube, etc., with a colour, or two or three different colours, preferably from end to end, so that if a short length is cut from a

bar of material, the specification for that material will be definitely known for as long a time as possible after the material has reached the workshop.

A series of different combinations of colours for each material is listed in the Inspection Leaflet 122, and is recommended for general adoption.

In addition, it is wise, when cutting short lengths of material for use or for issue to the workshops, to cut from the end opposite to the one carrying the manufacturers' identification marks and inspection stamp, so that these records may be retained for as long as possible. Where stores indents and job cards are used, such material identification references

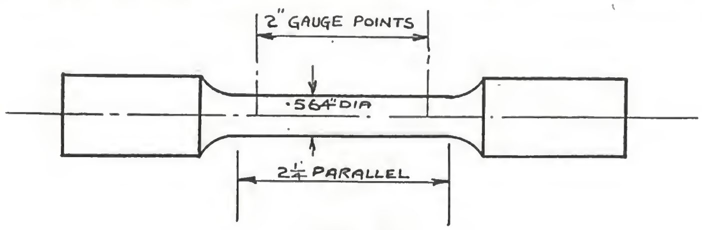


FIG. 26

should be quoted thereon as will serve to identify the material for as long a period as possible.

TESTING METALLIC MATERIALS

One of the most essential points in testing materials is that the piece or pieces selected must be truly representative of the bulk.

In testing bar material, a typical specification lays down that the bars must be from the same cast and grouped in parcels of not more than 100. Thus assured, the inspector selects one from each parcel, which is machined and tested to the requirements of the specification. If this sample complies with the necessary requirements, the whole parcel may be approved and stamped.

In the case of certain steels, dependent upon the specification, a specimen is taken as above, and in addition to the tensile test is Brinell tested. Assuming that the tensile test results and the Brinell figure are satisfactory, the remainder of the bars are then Brinell tested, and if the figures obtained are consistent with that obtained for the original specimen, it indicates that the bars are homogeneous and satisfactory in this respect.

To illustrate this principle still further, the instance of castings may be taken. If castings are large, one test sample is cast to represent each casting. If castings are so large as to require more than one charge, and the charges are not mixed prior to casting, a test sample is cast to represent each charge.

With small castings a test piece is cast to represent a certain weight of the metal poured, say, for every 100 lb.

The specifications for steels lay down that the material shall conform to a certain chemical analysis, and have particular mechanical properties after being cold-rolled or heat-treated, etc. It is stipulated that the complete analysis of the cast from which the bars are produced shall, on request, be supplied to the inspector. The determination of the chemical composition is the work of a specialist in chemistry and not that of a ground engineer.

Further, while it is not essential that a ground engineer in this category shall himself be able to carry out the mechanical tests called for in the specification, it is important that he should possess sufficient knowledge of mechanical testing to enable him to deal in a technical manner with the

results stated in the test reports, and satisfy himself from these reports that the material conforms to the requisite specification in all respects.

The usual mechanical tests called for in a specification for steel bar are those of tensile, nicked fracture, izod or impact, and hardness tests.

The tensile test consists of pulling and breaking a prepared length of the steel in a suitable testing machine, and during the test, and afterwards, determining values representing certain of the mechanical properties of the steel. A typically prepared length, and one of those adopted by the British Standards Institution, is shown in Fig. 26. Here it should be noted that the portion of the specimen considered for calculation purposes is that between the marked gauge points. The diameter of ·564 in. is taken

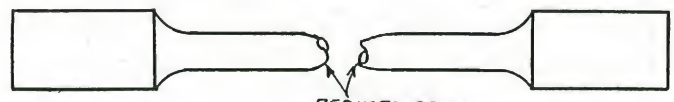


FIG. 27

for convenience, because the calculated area of a bar of this diameter is exactly ·25 square inches. The broken pieces of the specimen after the test are shown in Fig. 27.

The ultimate tensile stress in tons per square inch is calculated by dividing the maximum load applied in breaking the specimen by the original sectional area in square inches. The yield stress is similarly calculated by dividing the load at which the material first commences to draw out or extend, with little or no increase to the load, by the original sectional area of the specimen.

The reduction of area per cent is equal to $\dfrac{A - a}{A} \times 100$, where $a =$ the area in square inches at the break, and $A =$ the original area of the specimen in the same units. The elongation per cent is equal to $\dfrac{1 - L}{L} \times 100$ where $1 =$ the length between the gauge points when the broken pieces are pieced together, and $L =$ the original length between the gauge points as shown in Fig. 26.

It is possible to show graphically the relationship between the various extensions and the different loads obtained as the result of any tensile test. A typical curve for a mild steel specimen is shown in Fig. 28.

This curve may be produced by plotting the actual figures obtained during the test, or directly while testing, if the testing machine is fitted with the recording apparatus.

In examining this curve, it will be seen that when the load is first applied, very little change takes place in the length of the specimen and up to the point marked B, if the load is removed, the specimen will return to its original length, and in so doing obeys what is known as "Hooke's Law." The stress at point B is known as the Elastic Limit, or the point at which Hooke's Law breaks down, and the specimen begins to take on a permanent set, or, in other words, just beyond this point the material becomes over-strained.

As further loading is applied, a point C is reached where the material stretches or extends considerably with no or very little increase to the load. This point is known as the Yield Point, and the stress at this point as the Yield Stress.

After this, it will be noted that the material extends more or less

proportionately as the load increases, until the ultimate stress is reached at the point *D*. Between the points *D* and *E* the stress appears to decrease. This actually is not the case, because the area of the specimen has become locally reduced, and therefore less load is required to maintain the necessary tension. Thus it will be seen that although the apparent stress at which the material breaks is recorded at *E*, the actual ultimate stress is recorded at point *D*.

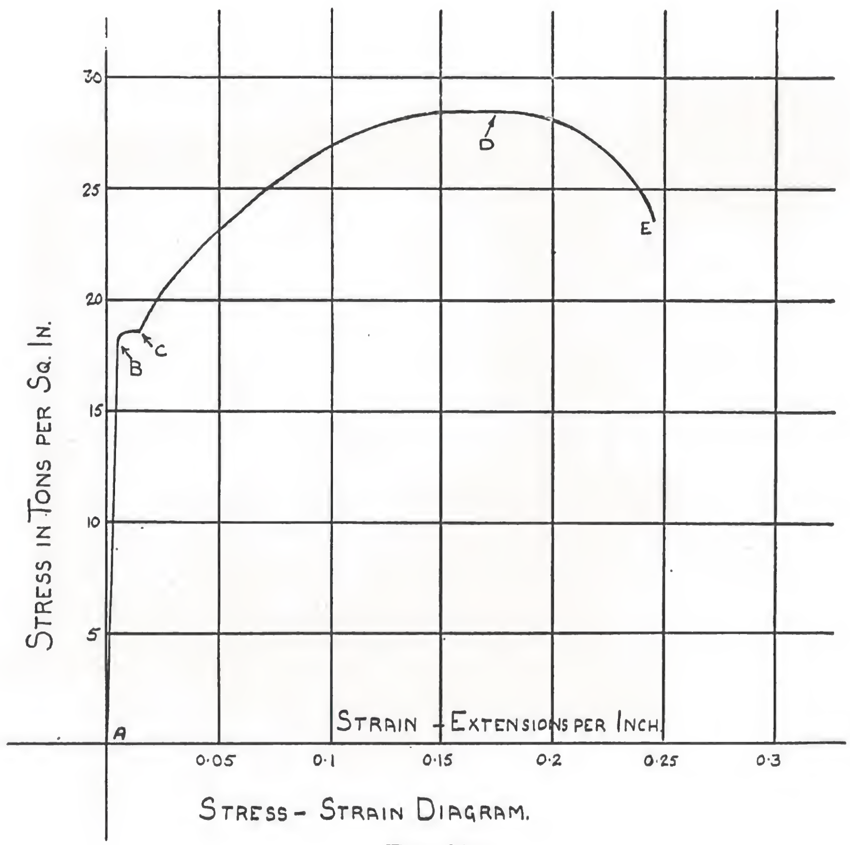


Fig. 28

Fig. 28A illustrates an Avery Universal Testing machine. It is of the vertical single-lever type, which is capable of carrying out Tensile, Compression, Bending, Shearing and Torsion tests. The main parts of the machine are as follows—

A. Specimen under tensile test.
B. Shackles carrying the gripping wedges securing the specimen.
C. Steelyard weighing lever.
D. Steelyard graduated in lbs. etc., indicating the load applied to the specimen.
E. Travelling poise weight with vernier scale attached.
F. Handwheel for moving poise weight along steelyard lever through gearing and screw *G*.
H. Column carrying fulcrum on which is balanced the steelyard lever. A diagrammatic view of the knife edges is shown in Fig. 28B.
J. Variable speed motor for applying strain to the specimen through gearing at *K*.
L. Lever operating motor.

M. Column at the top of which are stops for steadying steelyard lever.
N. Pointer indicating neutrally poised position of steelyard lever.
O. Autographic load-extension recorder which is an optional fitment.
P. Additional attachments for compression, bending tests, etc.

Assuming the tensile specimen already gripped in position for testing as shown in Fig. 28A, operations are commenced by applying strain with the motor and simultaneously, if necessary, moving the poise weight from

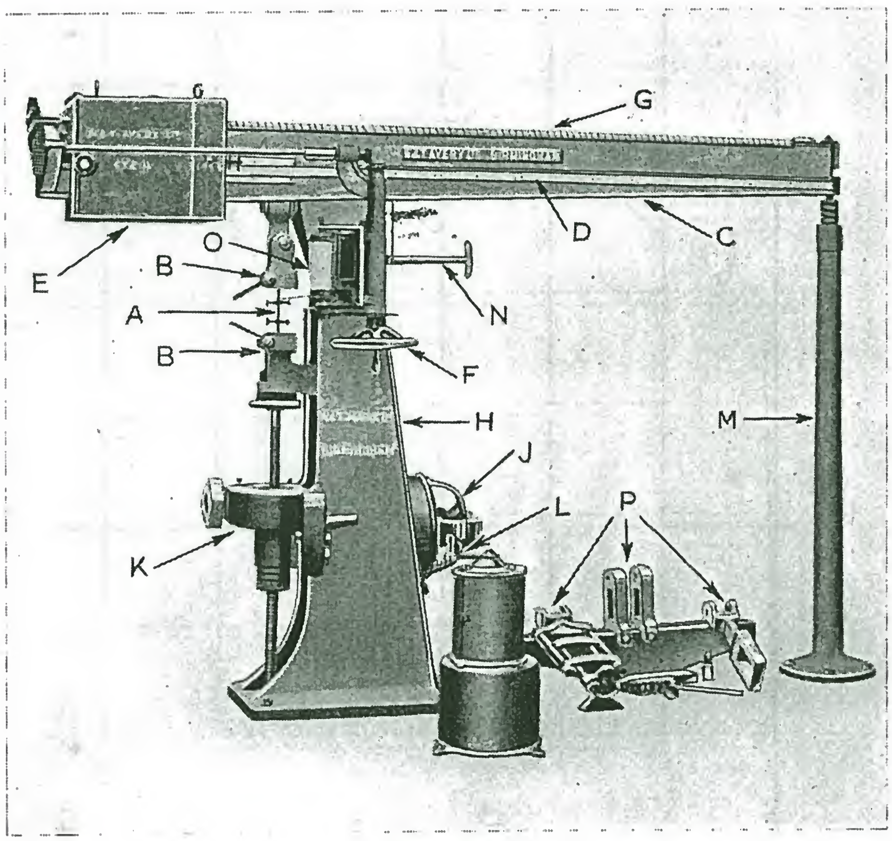


FIG. 28A

its zero position along the steelyard lever, by means of handwheel and lever movements, which are so made that the steelyard lever remains poised approximately midway between the stops at the top of the column *M* until the specimen is broken. This condition is best obtained by the operator watching the movement of the pointer indicating the neutrally poised position.

The lever may bear on either of the stops at different periods of the test, but when it does so, the poised position is again obtained by use of the motor or poise weight handwheel, i.e. applying more strain to the test piece when the steelyard is on the bottom stop, or by moving the poise weight, i.e. increasing the stress in the test piece when the steelyard is on the top stop.

The poise weight may be divided into two parts, the smaller portion of which, in conjunction with a second graduated scale on the steelyard,

will give readings from zero up to 2 tons. Thus finer sub-divisions are obtained for low capacity tests.

It should be noted that when testing such materials as mild steel, that is, if a load extension diagram is being recorded, it will be necessary for the poise weight to travel backwards towards zero position after the maximum stress has been reached. See Stress-strain diagram in Fig. 28 between the points D and E.

Nicked Fracture Test

A representative specimen is nicked or sawn, leaving the area of the part to be fractured at least equal to half the sectional area. The specimen

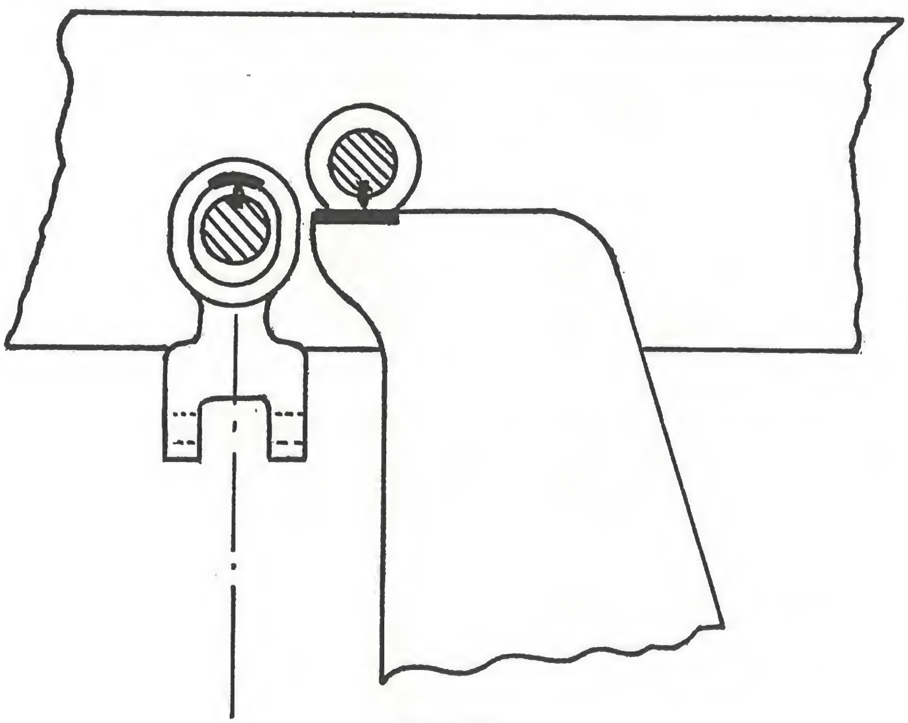


FIG. 28B

when broken by a minimum number of hammer blows shall show a fracture of the type described in the specification.

Hardness Testing

In the various B.S. and D.T.D. Specifications, a Brinell (or other approved) Hardness test is called for. In addition to the Brinell Hardness Tester, the Vickers Diamond, Rockwell, and Firth Hardometer Testing machines have been approved for use.

1. BRINELL TESTER

On this machine an impression is made on the specimen under test with a 10 mm. diameter ball, the load being applied by means of oil pressure. The total load on the ball is equal to 3,000 kg., and is maintained for not less than 15 sec. The diameter of the impression is then measured and the equivalent hardness number is taken from a schedule of factors laid down for the test. There is generally a relationship between the

Brinell hardness number and the equivalent tensile stress for the purpose of steels only. As an example, supposing a heat-treated alloy steel has a Brinell number of 300. The equivalent tensile stress is equal to $300 \times \cdot 22 = 66$ tons per square inch. There are other factors for the particular kinds of steel involved. In the case of lighter gauge materials, a different diameter of ball should be used, and a lighter load applied, but it should be remembered that Brinell impressions should never be made where the mass of the material is not sufficiently adequate to stand the load without damage to the part being tested.

2. Vickers Diamond Hardness Testing Machine

This machine is used for testing all kinds of metallic materials, but is particularly suitable for the testing of thin steel tubing, strip, sheet, and case-hardened steels. The standard loading is 30 kg., which may be reduced to 5 kg. for thin materials, and provided the material under test is homogeneous, the value of the hardness numeral obtained is not affected by the change of loading.

3. Rockwell Machine

The load in this case may be applied either through a small ball or a conical diamond. The hardness values obtained are only correlated with the tensile properties of the material from comparative tables compiled from previous observed data for each type of material. The hardness numbers cannot normally be correlated with the tensile stress as in the case of a Brinell machine.

As an instance of its application, supposing a number of sections or parts are to be rolled from a particular coil of strip and afterwards heat-treated. Before commencing operations a specimen is cut from the strip and heat-treated in the manner prescribed for the sections or parts. This specimen is then fully tested to the requisite specification and the Rockwell figure determined.

Assuming that the specimen complies with the specification, and that the Rockwell number is 70, then if the Rockwell numbers of the sections or parts after heat-treatment come within ± 2 of this number, it is a reasonable assurance that the heat-treatment of the parts has been carried out correctly, and that their tensile strengths are correct.

4. Firth Hardometer

This machine is similar in principle to the Brinell machine, with the exception that the load is applied through the compression of a spiral spring operated by a hand-wheel. The loading used is either a 120 kg. or a 30 kg. spring box. For the harder materials a pyramidal indenter is provided in addition to the hardened steel ball, the numbers obtained with the diamond and steel ball respectively being comparable as shown in the table supplied with the instrument.

Impact Testing

When this method of testing was first applied to aircraft materials, the results obtained were considered to give an indication of the toughness of the material, or its power to resist shock. Instances occurred where bolts, when subjected to working conditions, snapped off just under the head, which bolts, when tensile tested, were found to pass this particular test satisfactorily. This confirmed the necessity for the Izod Impact Test. The test has since proved to be of greater value, as it has been found to

reveal indications of incorrect heat-treatments and unsatisfactory chemical composition of the various materials. If, for instance, the impact value of a steel is low, it may indicate that the steel has been incorrectly heat-treated, but if there is no doubt regarding the heat-treatment, the question of analysis might be investigated.

The type of machine most commonly employed for impact testing is

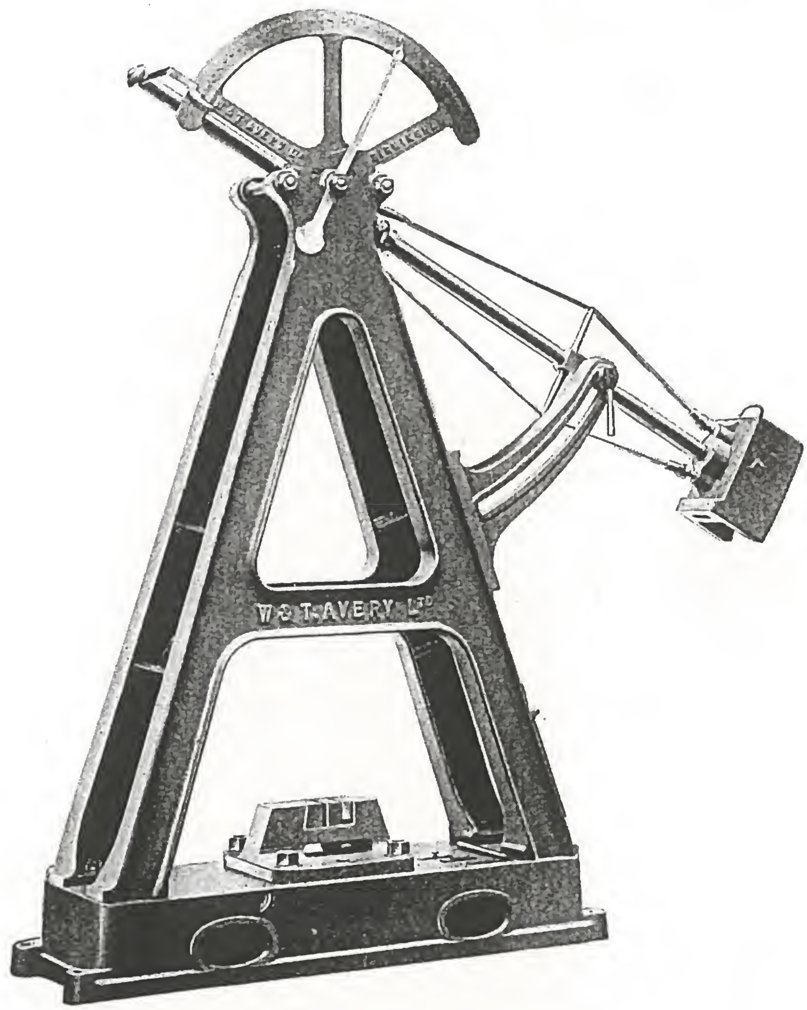


FIG. 29
(By courtesy of W. & T. Avery, Ltd.)

shown in Fig. 29, and the types of test specimens generally adopted are illustrated in Fig. 30. It will be noted that the longer specimens have three notches, so that the average of three tests may be taken, giving results which are more conclusive. The method of carrying out the test is as follows.

The specimen is held in the gripping dies with the notch facing the direction in which the pendulum is to swing when released. The pendulum is then allowed to swing, and at the lowest point in its travel breaks the specimen held in the grips, and proceeds to rise on the other side similarly to a clock pendulum, but to a lesser height than that from which it was

released owing to energy having been absorbed in breaking the specimen. To explain simply—supposing that the vertical height of the pendulum before release is 1 ft. above the striking point on the specimen, and that the weight of the pendulum is 120 lb., assuming the weight to be concentrated at the striking knife edge, and that the vertical height of the pendulum on the other side and at the end of the swing is only 6 in. above the striking point, then

The potential energy of the pendulum before release . . . . . $= A = 120\text{ lb.} \times 1\text{ ft.} = 120\text{ ft.-lb.}$

The potential energy of the pendulum at the other end of the swing . $= B = 120\text{ lb.} \times \frac{1}{2}\text{ ft.} = 60\text{ ft.-lb.}$

Then $A - B = (120 - 60)\text{ ft.-lb.}$. $= 60\text{ ft.-lb.}$

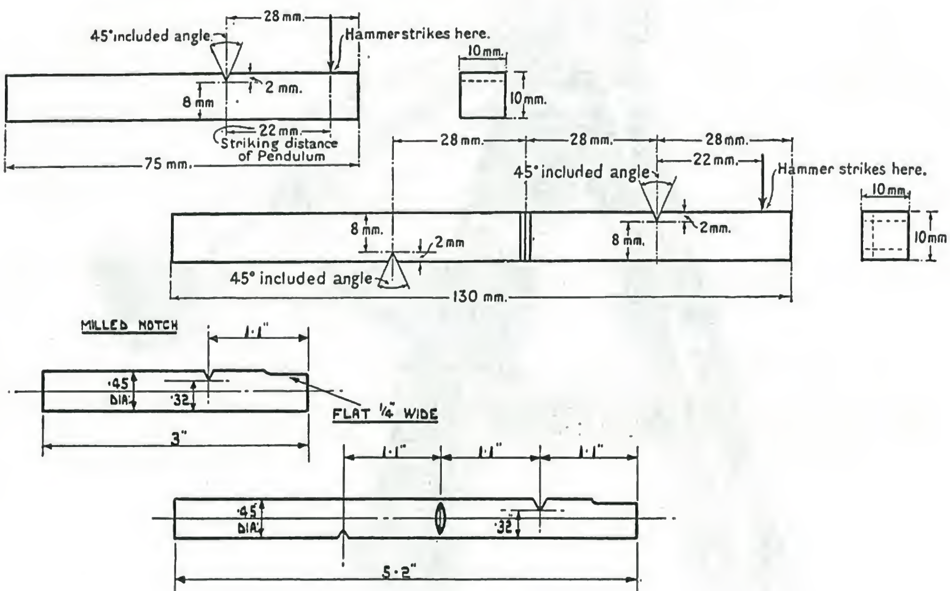


FIG. 30

which is the amount of energy lost by the pendulum in breaking the specimen, and represents the Izod or impact value of the material under test.

To avoid making calculations when testing, the number of foot-pounds representing the impact value of the specimen is registered directly by the pointer which is made to swing over the graduated quadrant, coming to rest at a figure corresponding to the Izod impact value.

Regarding the testing of materials, the candidate would be well advised, whenever possible, to obtain practical experience of testing, coupled with the study of some standard work on material testing.

CHARACTERISTIC DEFECTS OF METALLIC MATERIALS

Under the existing system whereby materials in the majority of cases are fully approved before release from the makers' works, the ground engineer does not generally have to examine such materials for defects until they have been machined or manipulated in the workshop. In any case he should acquaint himself with the nature of the common defects

to which metals are liable in order to ensure that only parts made of sound materials are passed for service on aircraft.

Steel

Steel bars, apart from errors in dimensions and straightness, may be found to contain such defects as *roaks*, *laps*, *cracks*, *seams*, *draw-marks*,

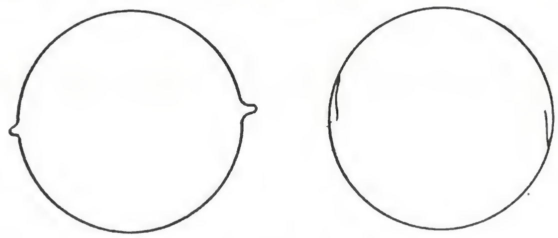


Fig. 31

and *piping*. Roaks may be caused by scale or slag being pressed into the steel and drawn out during rolling. They may be detected by filing or machining the surface of the bar, when they generally appear as dark-

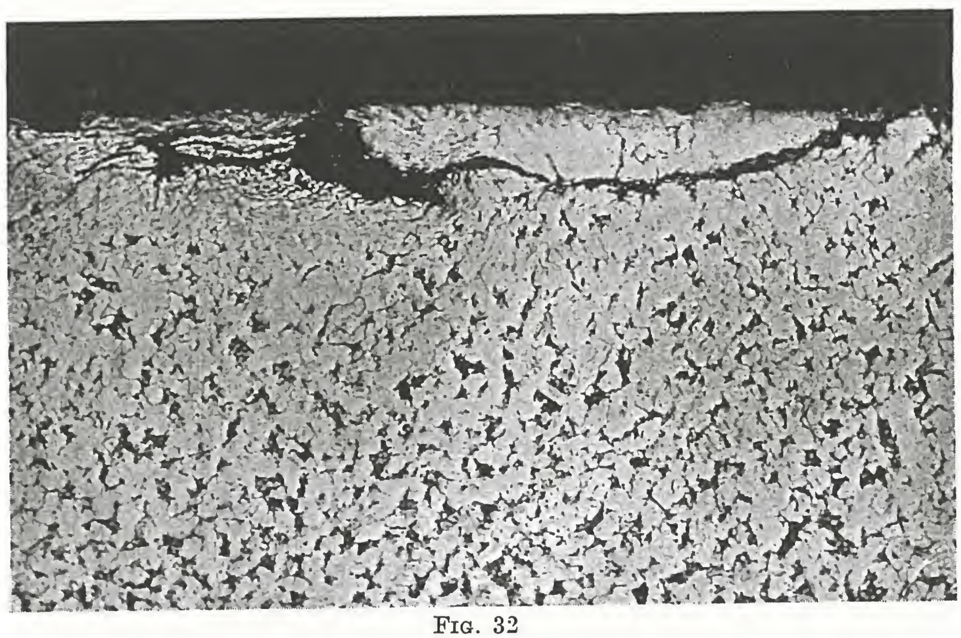


Fig. 32

150 × magnification

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coloured lines. The further defect of cracking may occur in a steel as a development from a roak.

Laps are caused by a *fash* or *fin* (see Fig. 31), which is bent over on to the steel and worked in during subsequent rolling. It is possible for them to extend through the whole length of the bar. If it is possible to remove them completely, or to machine out the part affected, the remaining metal will be useful.

Cracks of various shapes occur in steel bars due to many and various

causes, and if the steel is suspect, and the cracks cannot be readily detected, they may be discovered by the aid of a magnifying glass, or more surely

FIG. 33
100 × magnification
(*R.A.F. Official. Crown Copyright reserved*)

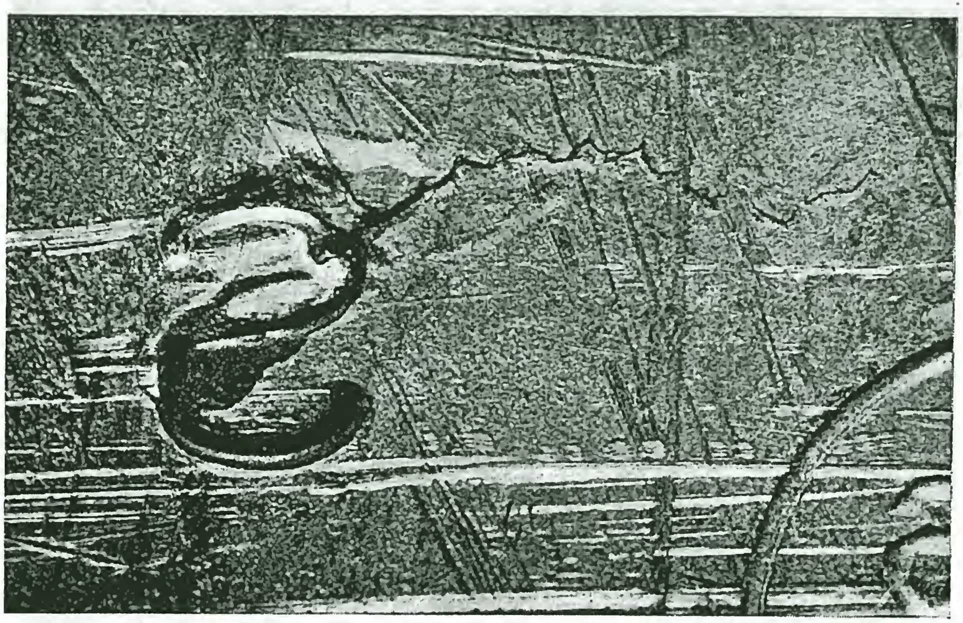

FIG. 34
10 × magnification
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shown by soaking the material in paraffin, wiping dry, and then coating the part with french chalk. The presence of paraffin on the chalk would

indicate the possibility of a defect. Steel parts, after hardening and tempering, should be examined for freedom from this defect.

Seams, which may be due to subcutaneous blow-holes or surface cracks in the ingot, run parallel to the length of the bar, and may generally be seen with the naked eye. Should any difficulty arise, however, one of the methods of detection described under "Cracks" should be adopted. Fig. 32 illustrates the transverse section of the edge of a 3.S.1 bar, showing a seam.

Draw Marks, which may be caused by dirt or foreign matter working on to the surface of the dies during the drawing operation, are serious if allowed to affect any ultimate work to which the bar is applied. An illustration of an unetched section of the edge of a streamline wire (5.W.3–S.80) shows deep draw-marks partially closed by subsequent rolling (Fig. 33). In this photograph the top part of the photo is solder, which is used for mounting the specimen.

Piping, which may cause defects in the finished bar, is due to axial shrinkage cavities formed in the ingot during solidification.

Defects in steel *Forgings* and *Stampings* may be due to original defects in the steel from which they are made, or which develop in the process of forging or stamping. The possible defects are *roaks*, *laps*, and *cracks*. The forgings or stampings are normally "pickled" to enable these defects to be detected, if they exist. It may be that in the course of machining, certain of the defects will be entirely removed.

Identification Marking. Although this is not strictly under the heading of steel defects, such stamp impressions as are made for the purpose of identification of the material or of the inspector passing the material, may be a source of trouble unless sufficient care is taken during the stamping operation. In Fig. 34 will be seen a crack which has developed on the surface of a fitting due to stamping a letter too heavily. In this connection, it is recommended that the designer should always indicate on the drawing the position on the fitting or part for identification stamping.

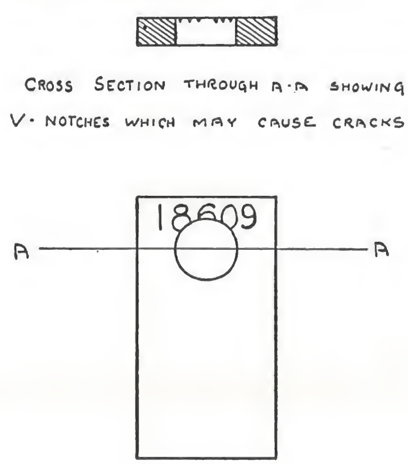


FIG. 35

Occasionally fittings or parts are drilled after identification impressions have been so positioned that the impression of a letter or figure is partly removed by the drilling, as illustrated in Fig. 35. This is bad practice, because it obviously leaves V-notches on the edge of the drilled hole.

Inspection stamps should, wherever possible, have an unbroken circular or oval border. Other markings should be stamped as lightly as possible consistent with legibility.

Steel Sheets or Strips should be examined for all surface defects, including *cracks*, *blisters*, *lamination*, and *buckle*. Lamination may be detected during the operation of a bend test, when the laminated parts will tend to separate. In the case of steel strip, buckle may not at first appear so serious, but if the strip has to be rolled or drawn to a particular section, kinks or even cracks may develop in the finished product due to this defect.

Steel Tubes. Apart from straightness and freedom from kinks, steel tubes should be examined for freedom from such defects as dirt, seaming,

grooving, and lamination. Fig. 36 shows the transverse section of a seam in a T.5 tube.

Aluminium and Aluminium Alloys

Sheet, Strip, Bars, etc., should be examined for freedom from *dirt specks, blisters, lamination, grooving, spills,* and *buckle.*

A spill, or what is sometimes known as a sliver (illustrated in Fig. 36A) is a surface defect in the nature of a flake of metal adhering to the parent metal, but partially separated from it by a layer of scale, oxide, or other form of non-metallic discontinuity.

Non-metallic inclusion is the original cause of this defect. Some of

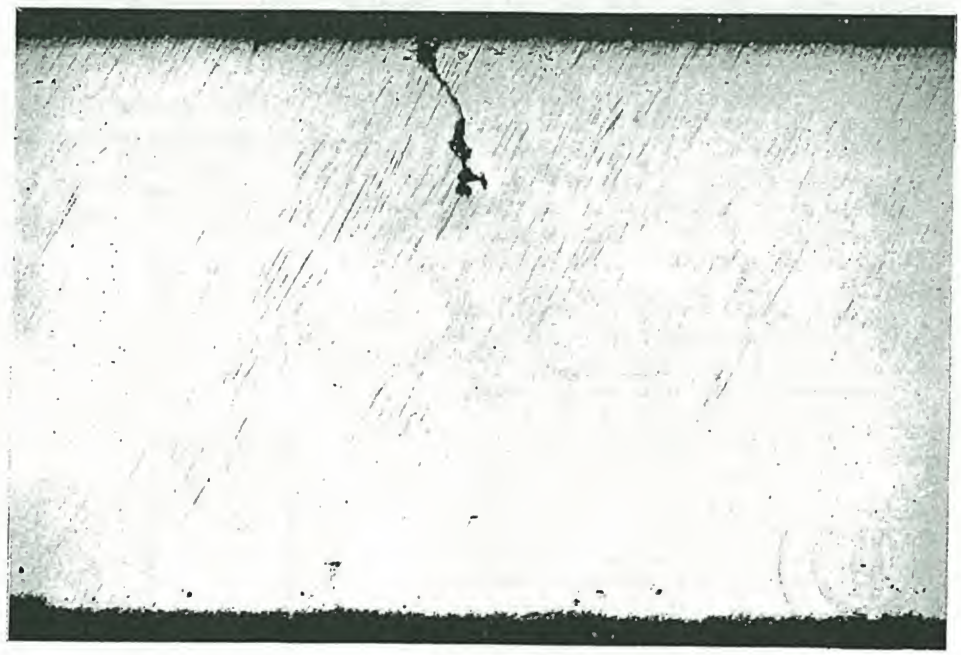


Fig. 36
200 × magnification
(*R.A.F. Official. Crown Copyright reserved*)

these defects may only be revealed after anodizing, which often is the means of showing up surface irregularities which were not detected previously by the naked eye. Small dirt specks are more obvious after anodizing than before, as the anodizing process will not act on such specks, although with careful examination they may be detected before anodizing.

The inspection of wrought duralumin occasionally provides a difficulty due to what appear as local laps or laminations on the surface of a finished part not being pronounced until the part has been anodized. To decide whether these apparent defects are serious or not must be left to the experience of the inspector, because at times they are purely local and may be regarded as insignificant, dependent upon the exact position they will assume in the structural member.

Forgings and *Stampings* should be inspected for such defects as *laps, cracks, offset,* and *insufficient metal.* Laps and cracks often become perfectly obvious after anodizing, a chromic stain appearing in the vicinity

of the defect. Here, again, if the defect is slight, it may possibly machine out, and in any case must be considered on its merits as affecting the strength of the part.

Castings made from any metal are liable to contain *blow-holes*, which are caused by gases being trapped while the metal is solidifying in the mould. Cracks, which may occur due to one of several reasons, are another defect which should be looked for in castings. *Porosity* may be detected by pressure testing in the case of castings on which it is possible to carry out this method of testing. This latter defect and blow-holes, if they cannot be seen from the outside of the casting, can be detected by radiological examination. For castings which are highly stressed, this

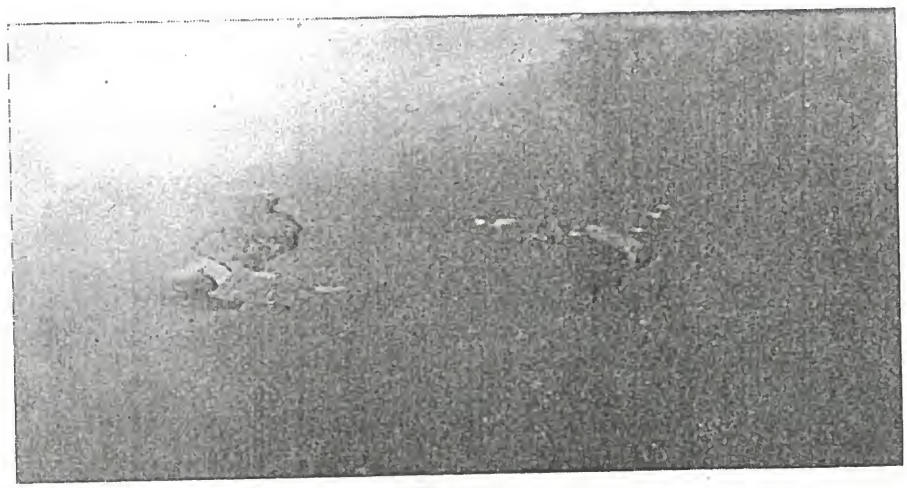


FIG. 36A

examination, or, alternatively, the application of a pre-determined proof-load, is imperative to ensure against failure under working conditions.

HEAT TREATMENT OF STEEL

The process of heat treating steel is one of the greatest importance. It must be remembered that aircraft fittings are designed to be as light as possible consistent with strength and resistance to vibration, etc., therefore too much emphasis cannot be placed upon the fact that when a competent authority has laid down a certain heat treatment for a particular grade of steel, the instructions should be rigidly adhered to. For instance, if the temperature range for the hardening of a certain steel lies between 900° and 925° C., if it is only heated to 850° C. it may not be hardened on cooling, and if it is heated to 950° C. some of its useful properties may be ruined.

For the measurement of high temperatures, thermo-couple pyrometers are more widely used than any others, but some accurate means of registering the temperature must always be used. This type of pyrometer consists in principle of two wires of dissimilar metals fused together, and in this form are known as a "couple." If the two metals are respectively connected to a millivoltmeter and then placed in a furnace, on heating an electric current is generated, the electromotive force of which varies with the temperature of the furnace. The couple is enclosed in a tube of silica or similar material, to prevent it being damaged in the furnace.

In order that readings may be taken directly without having to convert, the millivoltmeter is calibrated to read in degrees of temperature.

Pyrometers should be frequently checked against the master pyrometer, and cross-checked at more frequent intervals against each other.

Optical pyrometers, and metallic salts of known melting points are also used for determining furnace temperatures, and are frequently used for checking thermo-couple pyrometers.

Normalizing, a treatment which is used so much in connection with B.S. Specification S.3, for mild steel sheet, means heating the steel to a temperature above its upper critical range, and allowing it to cool freely in air. The steel should be maintained at the required temperature for about 15 min., depending, of course, on the bulk of steel under treatment, and the temperature should not exceed the upper limit of the critical range by more than 50° C. The purpose of normalizing is to remove the internal

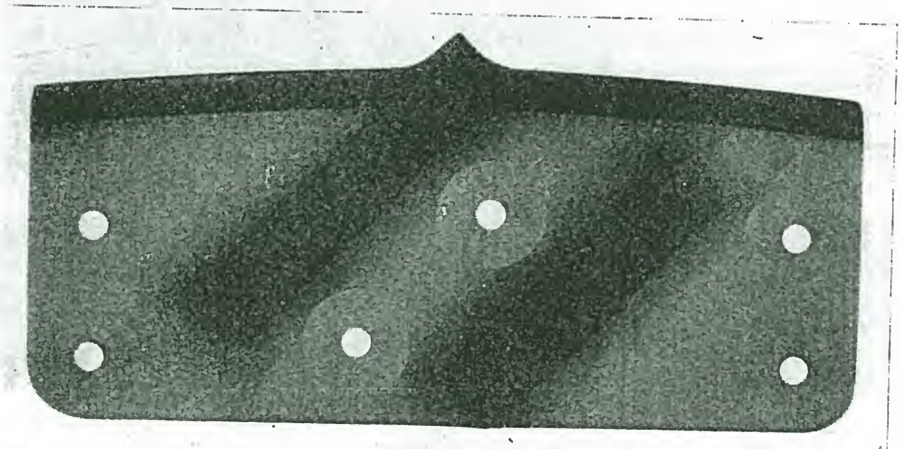


Fig. 36B

stresses set up by welding or bending, and to make the structure of the material uniform throughout.

Annealing consists of heating steel to any predetermined temperature and allowing it to cool slowly.

Hardening consists of heating the steel to a temperature exceeding its upper critical range and cooling it more or less rapidly in water, oil, or air.

Tempering consists of heating the hardened steel to a temperature below the carbon-change point, with the object of reducing the hardness and increasing the toughness.

Case-hardening. The object of case-hardening is to produce parts which have very hard cases with a high carbon content, while the cores, with a low carbon content, remain more or less ductile. The process is carried out by surrounding the parts to be case-hardened with a carburizing material, and heating to a temperature similar to that described for hardening, for about four hours, or such time as will give the required thickness of hard case. At the end of this time, the parts are allowed to cool down slowly in the box in which they were treated.

The parts are then refined by heating to a temperature of between 850° C. and 900° C., at which temperature they are rapidly cooled in water

or oil. The cooling is followed by again heating the parts to a temperature between 750° C. to 800° C. and requenching in order finally to harden the cases.

WELDING OF STEEL PARTS

In addition to the final examination of the welded fittings, it is essential that the processes and materials used in the production of the fittings are satisfactory.

The parts before welding should be clean and free from scale; the welding wire should be of an approved quality, and the gas tested daily by the following method, where gas generators are used.

A piece of white blotting-paper soaked in a 10 per cent solution of silver nitrate should have the gas blown on to it. If, as a result of the blowing, no change in the colour of the blotting-paper is observed, purity of the gas may be assumed. But if the blotting-paper turns brown of any shade, the gas should be changed immediately.

If dissolved acetylene gas is employed, the purity test may take place at longer intervals.

Periodically it is imperative to check, by means of test-pieces, the efficiency of the welder. Dependent upon the class of work being welded, the operator should make the following specimens—

1. Butt welds for tensile and bend tests. The tensile specimen should not break at the weld, while the latter specimen should show no signs of brittleness when bent at the weld.
2. Tube to sheet weld.
3. Tube to tube weld.

(2) and (3) should be sectioned and show a satisfactory depth of weld penetration. For full tests, see Inspection leaflet 39.

In the examination of a welded fitting, it must be visually ensured that a satisfactory joint has been made, and that the material added through the medium of the welding wire is sufficient to form a continuous fillet of regular thickness, and that the bond and penetration are satisfactory.

After welding, the parts should be heat-treated, unless the drawing states otherwise. The heat treatment should be that called up in the relevant specifications for the materials. Special instructions must be sought regarding the question of treatment of a fitting consisting of steels, each requiring a different heat-treatment, as the strength of the one may be impaired by the heat-treatment required by the other.

Subject to drawing requirements, parts made from non-corrodible steels to D.T.D. Specifications Nos. 171, 176 and 207 may be used as welded without subsequent heat-treatment. Non-corrodible steel to D.T.D. Specification No. 166 may be edge and spot welded without subsequent heat-treatment, but the strength of the steel in the vicinity of the weld will be reduced to that of steel to D.T.D. Specification No. 171.

Non-corrodible steels must be welded with rods to D.T.D. Specification No. 61, or with rods of approximately the same composition as the material being welded.

All corrodible steels must be welded with iron or mild steel rods to D.T.D. Specification 82 or with rods of approximately the same composition as the material being welded.

RADIOLOGICAL EXAMINATION
(" X-Ray ")

The extended application of light alloy castings to the stressed parts

of aircraft calls for a more stringent examination of castings than was hitherto the case, and when proof loading is impracticable, "X-ray" examination becomes indispensable.

Fig. 36B illustrates a photograph from a radiological negative of a good casting, and Fig. 36C that of a bad casting, as there is clear evidence of porosity.

The special applications of this examination include castings, forgings, and welded parts in which there is reason to suspect non-metallic inclusions, blowholes, etc.

Certain firms are experienced in this method of examination, and can arrange for certification of parts approved thereby.

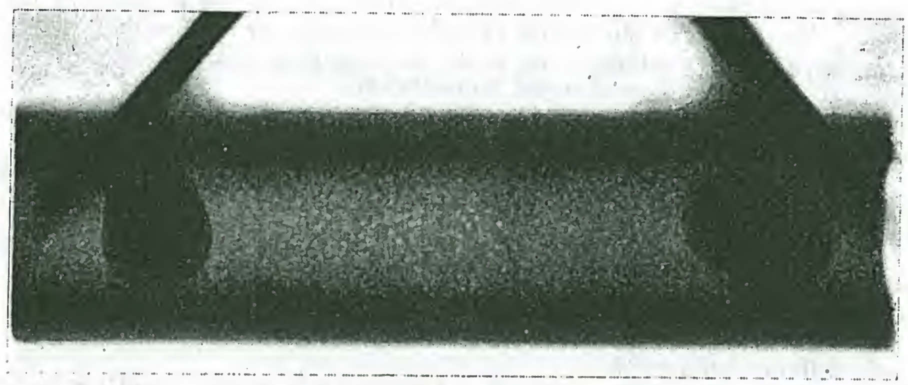


FIG. 36C

SOLDERING AND BRAZING

It is very essential that parts involved in soldering and brazing should be thoroughly cleaned by some mechanical means if possible. Where pickling is resorted to, special care should be taken to remove the acid by washing the parts in boiling water, and afterwards heating the parts concerned to a temperature of 150° C. The use of an acetylene flame is definitely forbidden.

The greatest care should be taken to prevent the overheating or burning of the material during the process, that the joint is completely filled with the solder, and that the solder is not run out by overheating. The preferable heating medium is a soft non-luminous gas flame, and in the case of tanks a copper bit must be used.

Soft Soldering

The soldering flux used must be one of an approved brand, and should be tested to ensure that it is free from mineral acid, to avoid the possibility of subsequent corrosion of the material concerned. The flux in use must be issued to the shops daily.

The test on liquid flux is carried out by dipping methyl orange paper into the flux after it has been diluted with an equal volume of water. Should the paper turn pink, mineral acid is indicated, and the flux is unserviceable. Flux in the solid form should be used in accordance with the manufacturers' directions, while fluxes derived from a jelly base must be forwarded for test to an approved laboratory.

Before commencing any soldering operation, it should be ensured that

the solder and the flux are of approved brands, and that the operation is as called for on the drawings.

The soft solder used should be either Grade "A" or Grade "B" of B.S. Specification No. 219/1925. Grade "A" is suitable for sweated joints on steel tubing and similar details. Grade "B" should be used for radiator casings and tanks, and generally for tin and coppersmiths' work.

Cadmium-zinc solder may be used as a substitute for soft solder, in which case suitable fluxes are soldering resin or soldering solution to D.T.D. Specification No. 81. In all cases the parts must be thoroughly washed subsequent to soldering to remove all traces of the flux.

Silver Soldering

This is so-called because the fusible medium consists of an alloy with a high percentage of silver. To form the joint the solder is applied by similar methods to those laid down under "Brazing." Borax is used as a flux, and the solder is most efficiently applied when the flux has been uniformly distributed over the heated surfaces forming the joint.

BRAZING

Whenever possible, a brazing and normalizing bath should be used, so that both operations can be carried out at the same time. The composition of the bath should be copper 55 per cent and zinc 45 per cent. The temperature of the bath should not exceed 900° C.

Sufficient zinc should be added periodically to make up for the loss of this metal by volatilization. A layer of borax and powdered charcoal on the top of the molten metal minimizes the loss of zinc.

Brazing without a bath should be carried out with a brazing metal having a melting point of 900° C., and after the operation is carried out the fittings should be normalized at 850° C. to 870° C. The brazing metal in this case must conform in composition to Grade "A" of B.S. Specification No. 263/1926. In this case a suitable flux is calcined borax.

CORROSION

Consistent with adequate strength, aircraft are designed to be as light as possible. For this and other obvious reasons, it is imperative that all aircraft parts should be protected against the possibility of corrosion.

All metals corrode if exposed to the atmosphere, to a greater or lesser extent, but aluminium alloys and steel suffer to a dangerous extent in this respect unless protected by an approved method. In the main, only the surfaces of the metals are attacked, but duralumin, for instance, is liable in addition to intercrystalline corrosion, which is much more deleterious than surface corrosion. Intercrystalline corrosion attacks the crystal boundaries, and its presence can only be discovered by microscopic examination, or bending the suspected part, the former method generally being impracticable, and the latter may so deform the part as to render it useless. The various methods of protecting metals are described in the following pages, a study of which is essential to the Ground Engineer.

The following general facts regarding corrosion should be noted by those associated with Design and Inspection—

1. Annealed duralumin, when in contact with normalized duralumin, will corrode rapidly.
2. The contact of dissimilar metals facilitates corrosion; instances of this are brass screws in duralumin, or duralumin riveted to steel. This is due to galvanic action.

3. Leather, when wrapped round unprotected metal parts, causes rapid corrosion.

4. Moisture or air that is at all humid aids corrosion. For this reason it is very essential that parts to be coated with paints or enamels shall be as dry as possible before coating. Cases are on record where painted metal faces have become rusty under the paint in consequence of the coating having been applied while the surface of the metal was wet when painted.

5. Dirt and foreign matter in any shape or form facilitates corrosion. As pointed out elsewhere in this book, cleanliness minimizes any prolonged action of corrosive deposits.

PROTECTIVE PROCESSES

Anodic Oxidation

This process is carried out to protect aluminium and aluminium alloys, including duralumin, against corrosion, and consists of forming an oxide on the surface of the parts so treated.

Briefly, the process is that of suspending the parts to be treated as anodes in an electrolyte, which consists of a 3 per cent solution of chromic acid in distilled water, or water which has been approved for the purpose. The chloride content must not exceed the equivalent of 0·20 grm. sodium chloride per litre. The cathodes are generally formed of graphite plates.

The solution will function satisfactorily with a strength of $2\frac{1}{2}$ per cent of chromic acid, and it is essential that the solution be checked from time to time to determine that the acid does not fall below this percentage. The temperature of the bath should be maintained at 40° C. $\pm$ 4° C. The bath should also be provided with some sort of mechanical stirrer in order to keep the solution circulating. Three to four amperes per square foot of treated surface is the current density generally employed.

The voltage across the bath is steadily increased from 0 to 40 volts during the first 15 min.; it is then maintained steadily at 40 volts for the next 35 min.; 40–50 volts for the following 5 min.; and is finally maintained at 50 volts for the last 5 min., the entire process lasting one hour.

The question of cleanliness is of extreme importance in this process, and the parts must be washed in petrol, benzol, or solvent naphtha, with a final washing in hot water and drying immediately prior to being treated in the bath.

After treating, the articles must be thoroughly washed in hot water and dried.

In the case of built-up parts, which are very liable to "pit," test samples must be treated with the parts and afterwards disintegrated to ensure absence of this defect.

"Pits" are formed as the result of air bubbles remaining between two adjacent surfaces of a built-up part, and where these bubbles exist, the current "arcs" across, and at the point of arcing, the metal is burned.

The test on the coating is usually that of visual examination, but a check test may be made by marking the parts with an indelible pencil or by the application of any cheap dye, which will not remove with a damp cloth if the coating is satisfactory.

Electro-deposited Zinc and Cadmium Coatings for the Protection of Steel Parts

The first step in ensuring that parts are efficiently coated by either of these processes is to examine the plating bath and its contents. The composition of the bath and its control should be such as to produce a satisfactory job.

Among the methods adopted for preparing the details for treatment are washing in a hot caustic bath, sand-blasting with fine sand, or polishing with emery. Cleaning by acid pickling should be avoided.

The electro-deposit process should not be applied to built-up strip and sheet steel parts, welded tubular components, and welded hollow components generally, from which it would be difficult to remove the last traces of the plating solution. These parts should be protected both externally and internally (unless the tubular members are closed at both ends) by means of stoving enamel, cellulose enamel, or pigmented oil varnish.

The thickness of the coating, which should not be less than ·0003 in., can be determined either by weighing the article before and after coating, or by definite measurement.

In order to remove any brittleness as the result of this process, the parts treated should be washed in cold water and heated for not less than 30 min. at a temperature between 100° C. and 200° C.

Check bend tests should be carried out on selected treated parts, and in the case of large parts a test piece of similar material should be plated simultaneously for the subsequent testing.

A check is also essential to see that the necessary limits controlling the fitment of the plated parts have not been exceeded due to the thickness of plating.

Stove Enamelling

This process consists of applying an approved enamel by dipping, spraying, or brushing, and afterwards heating the coated part in a special stove at a temperature not exceeding 170° C. for approximately 2½ hours. This temperature limit is important, because of the soft solder on soldered parts melting at approximately 180° C., and in consequence of this the temperature should be very carefully controlled. Two thermometers should be in constant use, one near the lower portion of the stove, and the other in the region of the enamelled parts. The parts to be coated should be cleaned with methylated spirit or other approved cleansing medium.

The enamel should be frequently checked for consistency and viscosity by means of a hydrometer, because the consistency of the enamel will vary in accordance with the evaporation of the volatile solvent. Approved thinners should be added when necessary.

It is particularly important to note that the parts being treated contain no trapped spaces, and for this reason there should be an exit through which the enamel may drain in cases of boxed-up or tubular structures.

It has been found that stove enamelling finally heat-treated duralumin decreases the ·1 per cent proof stress and ultimate tensile stress figures. In consequence of this a representative test specimen should be heat-treated and stoved with each batch of duralumin parts to ensure that the test figures do not fall below those required by the specification for the material.

ALUMINIUM AND OTHER LIGHT ALLOYS

Aluminium in the form of sheets is now extensively employed on aircraft for such substructures as fairings, cowlings, and brackets. It is also used in the form of tubes in places where stress is not of importance. It has a specific gravity of 2·6, which, for equal volumes, is one-third of the weight of steel. The sheets, which consist of not less than 98 per cent

pure aluminium, are used in the hard, half-hard, and softened conditions, which have the following tensile strengths—

Hard,	not less than 9 tons per sq. in.
Half-hard,	not less than 7 tons per sq. in.
Softened,	not less than 5 tons per sq. in.

The softened sheets are very adaptable for spinning, and in the hard condition are largely used for the shells of petrol and oil tanks. The only tests called for in the relevant specifications are those of tension and bending, although all of the sheets are examined for freedom from surface defects and buckle, also that they are bright, clean, smooth, and free from discoloration, blisters, and lamination. The limits of thickness laid down vary from $\pm$ ·001 in. for a thickness of ·012 in., to $\pm$ ·018 in. for a thickness of ·3 in.

The use of pure aluminium, however, is limited, owing to its low tensile strength. Light aluminium alloys are, however, used in the form of bar, sheet, strip, tube, forgings, and castings. In the wrought condition, the light aluminium alloy known as duralumin has a chemical composition of—

Copper,	between 3·5 and 4·5 per cent.
Manganese,	between ·4 and ·7 per cent.
Magnesium,	between ·4 and ·7 per cent.
Silicon,	not more than ·7 per cent.
Iron,	not more than ·7 per cent.
Titanium,	not more than ·3 per cent.
Aluminium,	the remainder.

Although the specific gravity of duralumin is only 2·85, yet it has the following mechanical properties—

·1 per cent Proof Stress,	not less than 15 tons per sq. in.
Ultimate Tensile Stress,	not less than 25 tons per sq. in.
Elongation,	not less than 15 per cent.

when the material is in the normalized condition.

In a similarly heat-treated condition, the ultimate tensile strength of sheet and strip in this alloy is not less than 25 tons per square inch, and a proof stress of not less than 15 tons per square inch.

The method of determining the proof stress of duralumin is similar to that laid down for high tensile steel, as may be gathered by comparing the curve in Fig. 36D with that in Fig. 38. When testing duralumin, the testing machine employed should possess an accuracy and sensitivity preferably within 5 per cent of the maximum load applied to the test piece.

The annealing and normalizing processes are dealt with under the section on "Heat-treatment of Duralumin."

Among the various aluminium alloy castings is that known as the "Y" alloy, which has a composition of—

Copper,	between 3·5 and 4·5 per cent.
Nickel,	between 1·8 and 2·3 per cent.
Magnesium,	between 1·2 and 1·7 per cent.

With certain small percentages of impurities, and
Aluminium the remainder.

This alloy casting has a tensile strength of not less than 10 tons per square inch in the "as cast" condition, and 14 tons per square inch in the heat-treated condition.

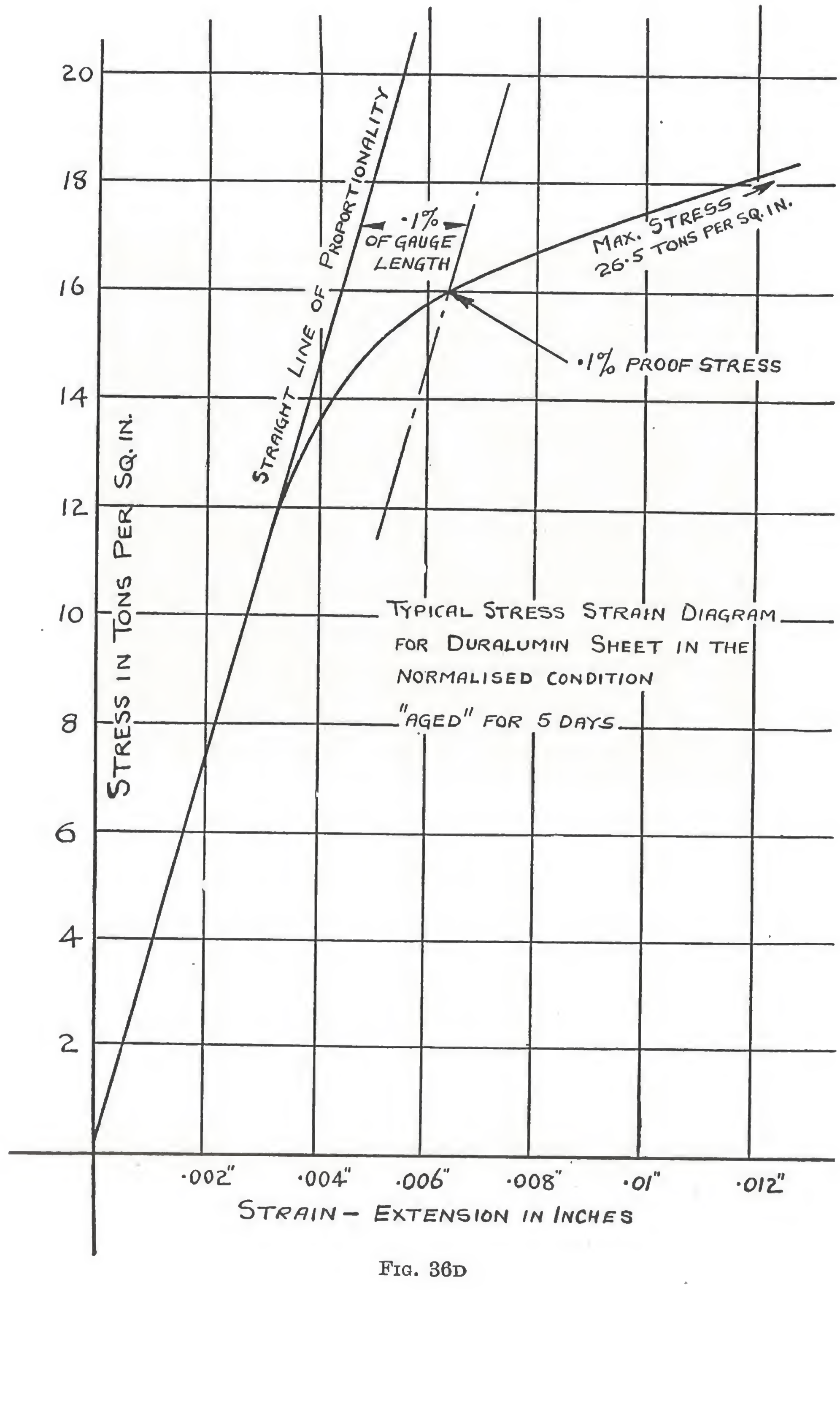

20
18
16
14
12
10
8
6
4
2
STRESS IN TONS PER SQ. IN.
STRAIGHT LINE OF PROPORTIONALITY
·1%
OF GAUGE LENGTH
MAX. STRESS 26·5 TONS PER SQ. IN.
·1% PROOF STRESS
TYPICAL STRESS STRAIN DIAGRAM FOR DURALUMIN SHEET IN THE NORMALISED CONDITION "AGED" FOR 5 DAYS
·002"
·004"
·006"
·008"
·01"
·012"
STRAIN – EXTENSION IN INCHES

FIG. 36D

The heat-treatment consists of heating the castings to a temperature of 500° C. to 520° C. for not less than six hours, and quenching in boiling water. The other varieties of this alloy contain varying amounts of copper and zinc, according to the particular specification, while an outstanding aluminium alloy casting has a silicon content of 10 to 13·5 per cent, the special feature of which is its resistance to corrosion.

The application of aluminium alloy castings to aircraft is dependent upon design, but should they be employed in any position where strength

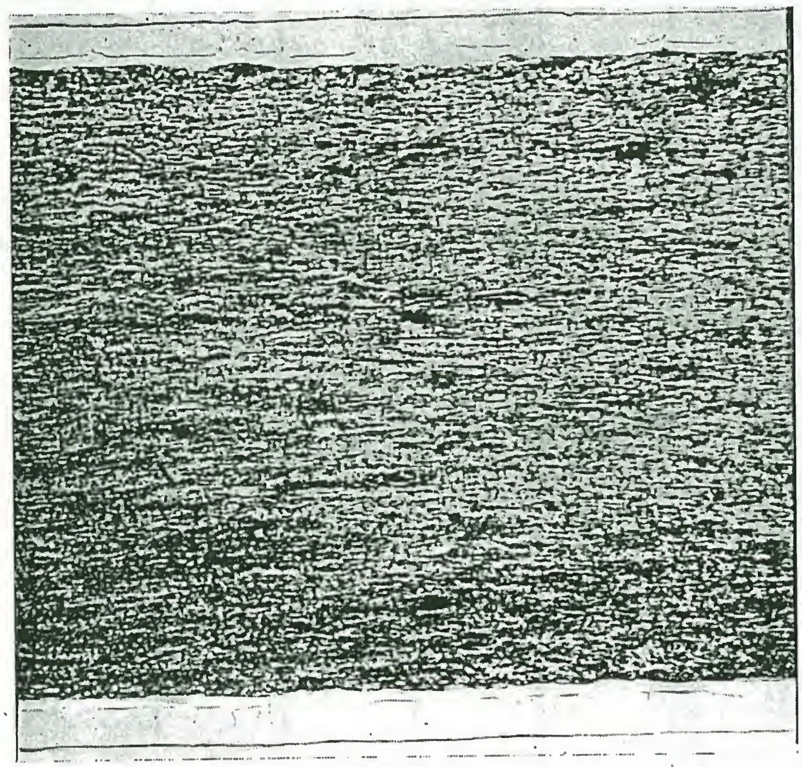


FIG. 36E

Full cross-section of 14 gauge "Alclad" sheet. Mag. 50X, Etched 1% HF.

is of importance; they should be radiologically examined for porosity and blow-holes, or, alternatively, subjected to a predetermined proof-loading.

ALCLAD

This product has been specially designed for use in aircraft, where a material combining light weight and high strength with exceptional corrosion resistance is of special importance. The sheet consists of a core of strong alloy, with a coating of high purity aluminium on each surface, which in addition to protecting the alloy where the covering is complete, also electrolytically protects the base metal when exposed at sheared edges or by deep scratches or abrasions. It also affords substantial electrolytic protection to rivets of the base metal.

It combines the properties of the strength of duralumin and/or super duralumin with the resistance to corrosion of aluminium. In the pure state aluminium offers a marked resistance to corrosion. Fig. 36E shows

a full cross-section of alclad. There is an intermediate diffusion zone between the strong alloy and aluminium which is due to the diffusion of copper and probably the magnesium-silicon constituent of the strong alloy into the pure aluminium during the manufacture and heat-treatment of the alclad. This diffusion takes place only at high temperatures.

Alclad is now used extensively for structural work in aircraft and for such parts as stringers and shell plating of hulls and floats in seaplanes.

Its specific gravity is not greater than 2·85.

The specifications covering Alclad are B.S.S. L.38 and D.T.D. 275.

The material to L38 should give the following test results—

Tensile Test

0·1 per cent proof stress (for sheets and strips thicker than 25 S.W.G. only)	not less than 13·5 tons per sq. in.
Ultimate Tensile Stress (all thicknesses)	not less than 24 tons per sq. in.
Elongation (on 2 in.) (for sheets and strips thicker than 12 S.W.G.).	not less than 15 per cent.

While the following figures are demanded for material to the D.T.D. Specification 275—

Tensile Test

0·1 per cent proof stress . .	not less than 16 tons per sq. in.
Ultimate tensile stress . .	not less than 26 tons per sq. in.
Elongation (for sheets and strips thicker than 12 S.W.G.) . .	not less than 15 per cent.

The following bend tests are applicable to both specifications—

Single Bend Test.

Applicable only to sheets and strips 12 S.W.G. (0·104 in.) and thinner.

Each test piece must withstand, without cracking, being bent through 180° round a radius of equal to three times the nominal thickness of the sheet or strip.

Ninety degrees Reverse bend Test.

Applicable only to sheets and strips 12 S.W.G. and thinner.

Each test piece is bent round a specified radius, dependent on the thickness of the specimen, at right angles to one end which is fixed in a vice. It is then bent back to the original position. This operation is repeated, and the specimen must withstand, without cracking, reversals ranging from one to nine, according to the thickness of the material.

The material is softened by heating to a temperature between 360° and 400° C., and cooling in air or water. All softened material must be finally heat-treated at 490° C. plus or minus 10° C. and quenched in water or oil.

ALPAX

This is a silicon aluminium alloy casting conforming to B.S. Specification L.33, with a specific gravity not greater than 2·7. This material is particularly useful when forming intricate castings, as the high percentage of silicon facilitates the flow of the molten metal. It has the following analysis—

Silicon between	10 and 13 per cent
Iron not more than . . .	0·60 per cent
Manganese not more than . .	0·50 per cent
Zinc not more than . . .	0·10 per cent
Titanium not more than . .	0·20 per cent

Total other metallic constituents (excluding those used as modifying agents)

Not more than	0·10 per cent

Total modifying agents (namely, sodium, tungsten, chromium, cobalt, boron and calcium)

Not more than	0·3 per cent
Aluminium	the remainder

The mechanical properties, if the alloy is sand cast, are as follows—

0·1 per cent proof stress not less than	3·5 tons/sq. in.
Maximum stress not less than	10·5 tons/sq. in.
Elongation not less than	5 per cent

whereas if cast in a chill mould, the following results may be expected—

0·1 per cent proof stress not less than	4·5 tons/sq. in.
Maximum stress not less than	13·0 tons/sq. in.
Elongation not less than	8 per cent

ELECTRON

This is a magnesium alloy which is now being extensively employed on aircraft for such parts as control wheels, axle blocks and chain guards. It has a specific gravity not greater than 1·83.

There are Specifications covering this class of material in the form of castings, sheets, bars and forgings.

D.T.D. Specification No. 59.A for castings requires a chemical composition of—

Aluminium not more than	8·5 per cent
Zinc not more than	3·5 per cent
Manganese not more than	0·5 per cent
Impurities not more than	1·7 per cent
Magnesium	the remainder

With a maximum stress of not less than 9 tons per square inch, and an elongation of not less than 2 per cent.

Magnesium alloy bars to D.T.D. Specification 259 have a chemical composition of—

Aluminium not more than	11·0 per cent
Manganese not more than	1·0 per cent
Zinc not more than	1·5 per cent
Impurities not more than	1·5 per cent
Magnesium	the remainder

and the mechanical properties are—

Up to 2 inches diameter:

Maximum stress not less than	17 tons/sq. in.
0·1 per cent proof stress	10 tons/sq. in.
Elongation not less than	10 per cent

Over 2 inches diameter:

Maximum stress not less than	14 tons/sq. in.
0·1 per cent proof stress	9 tons/sq. in.
Elongation not less than	5 per cent

HIDUMINIUM

This aluminium alloy to B.S.S. Specification L.40 is supplied in the form of bars, extruded sections, and forgings.

It is commonly known as "Hiduminium RR 56." The specific gravity is not greater than 2·8. It has a chemical composition of—

Copper,	between 1·5 and 2·5 per cent.
Nickel,	between 0·5 and 1·5 per cent.
Magnesium,	between 0·6 and 1·2 per cent.
Iron,	between 0·8 and 1·5 per cent.
Titanium,	not more than 0·2 per cent.
Silicon,	not more than 1·0 per cent.
Aluminium,	the remainder.

When intended for aeronautical purposes, it is subjected to the following heat-treatment—

It is heated uniformly to a temperature between 510° and 535° C. and quenched in water, and afterwards aged by heating between 155° and 175° C. for 10 to 20 hours. This ageing may be accelerated by heating at a temperature between 195° and 205° C. for a period not exceeding 2 hours.

After this treatment and ageing, it must conform to the following mechanical tests—

0·1 per cent proof stress .	not less than 21 tons per sq. in.
Ultimate tensile stress .	not less than 27 tons per sq. in.
Elongation . . .	not less than 10 per cent.

Hardness tests are carried out on the representative test pieces, and the hardness of the bars, forgings, or extruded sections shall not be more than 10 per cent less than that of the test piece.

Other specifications provide for this class of material in the form of castings.

HEAT TREATMENT OF DURALUMIN

For the purpose of working, bending, and workshop manipulation, the duralumin should be annealed, which consists of heating the material in a salt bath to a temperature of 380° C. ± 10°, and cooling in air, and after working, normalizing at a temperature of 490° C. ± 10° C., after which it should be cooled off in water. The normalizing temperature should never exceed 500° C., as there is a danger of embrittling the material. This latter precaution is equally applicable to Alclad.

For simple bends or slight working, the material may be in the normalized condition, but the cold working must be completed within two hours of quenching. For more drastic working duralumin should always be annealed.

Rivets are used only in the normalized, or finally heat-treated, condition. Immediately before use they should be soaked at the normalizing temperature for a period of 15 to 30 min., and the riveting completed within 1 hr. after treatment.

Duralumin should never be left in the annealed condition for service on aircraft; it is much weaker than in the normalized condition, and further. is much more liable to corrode.

The reason for the time limit stipulations regarding the working of duralumin is that after normalizing the material "ages" or hardens; at first fairly rapidly, and then slowly. If drastically worked after age-hardening, cracks may develop.

The temperature for forging or stamping duralumin should be between 400° C. and 450° C., but never below 400° C., or cracking generally occurs.

HIGH TENSILE STEELS

Concurrent with the development of "all-metal" aircraft, came the extended application of high tensile steels to their construction. From the weight standpoint, low or medium carbon steels of a comparatively low tensile strength were ruled out of the question. Plain high carbon steels could be hardened and tempered to a degree which would give them sufficient strength, but they would not be sufficiently ductile for the required degree of manipulation, or for the work to which they would be applied.

The employment of steels which rely for their improved mechanical properties on the addition of comparatively small amounts of such elements as nickel, chromium, manganese, tungsten, molybdenum, and vanadium, became very popular, and that popularity has been maintained.

The addition of nickel, besides generally improving the qualities of the steel, definitely increases the toughness, and raises the elastic limit. Case-hardening steels, which are mainly used for engine parts, contain from 3 per cent to 5 per cent of nickel. Chromium increases the hardness of steel, and gives to it that quality known as "air hardening." Stainless steels contain not less than 12 per cent of chromium. Tungsten imparts air-hardening qualities and increases the ability of the steel to retain its hardness and strength at comparatively high temperatures. Other elements are added in varying amounts, to obtain improved results and special characteristics, for instance—

·25 per cent Vanadium
·65 per cent Molybdenum
1·0 per cent Tungsten

when added to steel avoids what is known as "temper brittleness," molybdenum being the most effective element in this respect. Sulphur and phosphorus are impurities in steel, and an excess of either, or both, causes the steel to be very brittle.

These steels, which are generally known as alloy steels, are now used extensively in the manufacture of spars, longerons, struts, and wing ribs of different sections, dependent upon the various designs.

In aircraft works, the steels for making the above parts are mostly worked in the form of strip as supplied by the steel maker. Dependent upon the specification, the strip may be supplied either in a fully heat-treated condition for forming or manipulating to the required section without further heat treatment, or in an annealed condition to be rolled or drawn to section and subsequently hardened and tempered. Using the former of these two alternatives, the aircraft manufacturer has no problem of heat treatment to settle, but with the latter, special methods of heat-treatment have had to be devised for dealing with the long lengths of the sections in question.

Small items made from steel in this form may be hardened and tempered in the normal manner, but with such sections as are used for spars, longerons, etc., even if furnaces of sufficient length were installed to cope with such parts, the difficulties of twisting or warping and of uniform cooling would be practically insurmountable if dealt with by the ordinary methods.

A brief description of the special methods of heat-treating such parts employed by Sir W. G. Armstrong-Whitworth Aircraft, Ltd., Coventry, and Messrs. Boulton & Paul, Ltd., Norwich, follows.

The Armstrong-Whitworth method of heat-treating steel strip and

sections formed therefrom is known as the "Tension Electric" treatment. It consists of heating the steel to the required temperature by placing the part to be treated in an electric circuit while the part is held in tension by special clamping dies secured at the ends of the part.

The resistance of the steel to the current causes the temperature to

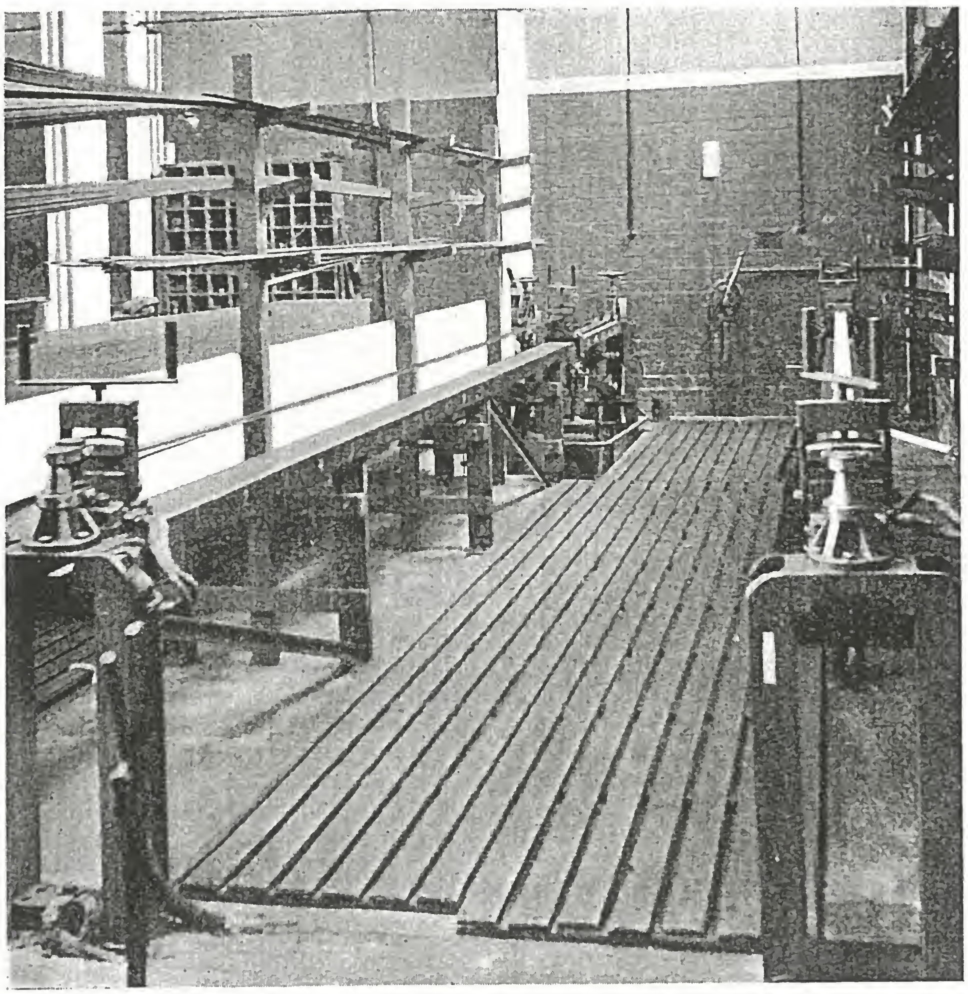


FIG. 37

rise quickly, and the complete heating operation for either hardening or tempering lasts only from one to three minutes, dependent upon the section under treatment.

The object of keeping the steel under tension is to prevent it from warping and twisting, and to counteract sag due to the weight of the section, which would naturally take place while the material was being subjected to the high temperature of hardening or tempering.

It is necessary to vary the voltage in accordance with the length of the part, and the amperage with the different cross-sections. Scale is only formed during the hardening process, but this becomes disintegrated during cooling. The reduction in thickness caused by the scaling is negligible.

Considering a 12 ft. length of 20 S.W.G. strip of typical air-hardening steel shaped in a manner suitable for a spar web about 2 in. overall width: it is hardened by heating to 880° to 890° C. by a current of 70 volts and 1,100 amperes, while under the tension of 1 ton per square inch. The current is only maintained for 1 min., and when cut off the part cools in the still air of the hardening shop while still under tension, or is subjected to an air blast, depending upon the size of the section.

After cooling, and while in the same gripping dies, a current of 31 volts and 240 amperes is applied for 1½ min. for the purpose of tempering at a temperature of 410° to 430° C., and again cooling in still air. The tension maintained during tempering and cooling is 8 tons per square inch.

The temperatures are checked by means of an optical pyrometer, salts, or standard thermocouple. The illustration in Fig. 37 shows two lengths of steel undergoing heat treatment.

Before the heat-treated part is passed for shop manipulation, it is tested on a diamond hardness-testing machine. Apparatus is also in existence for hardening and tempering by the above method, but including water or oil cooling.

CONTINUOUS HEAT TREATMENT PROCESS

The Boulton & Paul continuous heat treatment process has been developed to provide for the heat treatment of steels after they have been formed into the desired section. The sections are formed either by rolling or drawing or a combination of both, whilst the strip is in the soft or annealed condition. On the completion of this forming process, the sections are passed through electrical furnaces, there being at the present time two distinct operations—pass for hardening, and one for the tempering.

For the heat treatment of, say, D.T.D. 54, the hardening furnace is set at about 860° C., which temperature is controlled automatically by means of a thermocouple, which is inserted permanently in the furnace chamber, this thermocouple operating an indicator which by being set at any predetermined reading will cause a cut-out of the electrical current when the desired temperature is reached, and likewise cause the current to be switched on again when the temperature falls below the predetermined value. In practice the instrument is sensitive to within about $\pm$ 3°.

At the entrance end of the furnace is a die through which the section is passed. The object of this die is to provide a certain amount of tension to the strip when it is being drawn through the furnace. At the outlet side of the furnace is a water-cooled die. The internal shape of this die is the exact shape required of the finished section, and by means of the cooling which takes place at this die the shape is retained.

The furnace and dies are mounted on the ordinary strip-forming drawbenches, and the passage of the strip through the dies and furnace is controlled in exactly the same manner as is the strip when being cold worked.

The operation of tempering is carried out in exactly similar manner, except that in this case the furnace is about twice the length of the hardening furnace, to ensure a satisfactory soaking operation.

TESTING HIGH TENSILE STEELS

The methods employed in testing high tensile steels closely follow those already described for mild steel, with the one important exception that a minimum proof-stress is called for in a number of the specifications of this class of material.

The proof stress is defined as the stress at which the stress-strain curve

departs by ·1 per cent of the gauge length from the straight line of proportionality. Other percentages of the gauge length are occasionally stipulated, but the principle of obtaining the proof stress is the same.

Comparing the stress-strain diagram shown in Fig. 28 with that shown

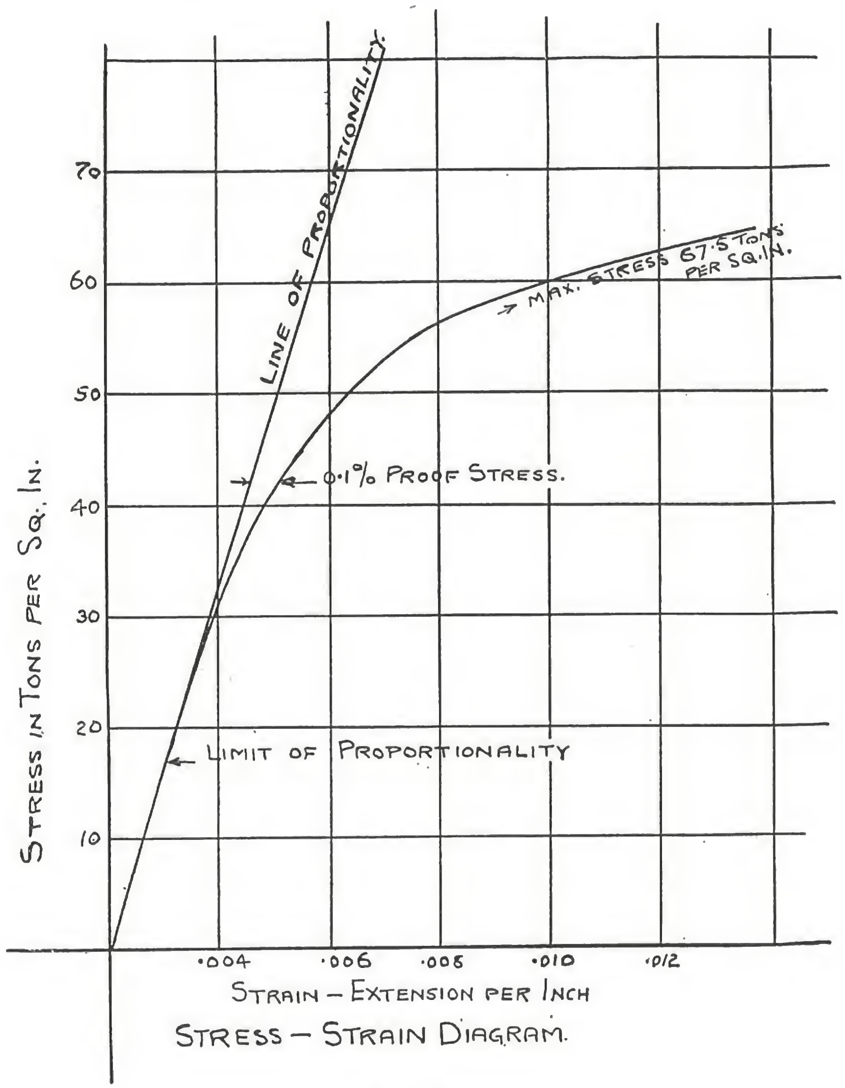


FIG. 38

in Fig. 38, it will be seen that the curve for high tensile steel in this instance is regular, and there are no points indicating elastic limit, or yield point, and it further illustrates the necessity for determining the proof stress as a means of demonstrating the elastic property of the steel.

The straight line of proportionality is drawn as nearly as possible through the portion of the stress-strain curve, which indicates the amount of extension of the specimen as proportional to the stress.

CHAPTER III

INSPECTION OF AIRCRAFT COMPONENTS BEFORE COVERING

There are special points which apply to the construction of each particular component, but the following notes will be of use on all components during the construction and inspection.

All struts should be straight within the limit of 1 in 600 for bow. Although this bow is allowable, it is preferable that the advantage of the limit is avoided. The cause of bowing is generally attributable to either uneven bedding at the ends of a strut, or the overtightening of the bracing wires, that is assuming, of course, that the strut was perfectly straight before insertion.

During construction any parts which will ultimately be hidden when the component is finally examined should be inspected at the time of fitment. If parts are drilled in position, before they are finally assembled, they should be removed for examination, or alternatively, a special inspection should be carried out before the bolts, rivets, or taper pins are finally inserted.

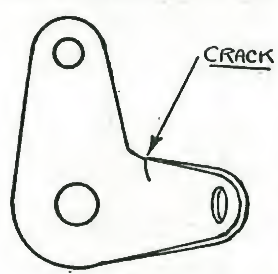


Fig. 39

Turnbuckles should have the threads completely engaged in the barrel, with room left for further adjustment, or, if of the fork-end type, the thread should be engaged beyond the inspection hole, and not so far as to foul the end fitting, and when finally adjusted, the turnbuckle should be locked in an approved manner with the locking wire.

The careful examination of fork-ends and bracing wires when in position is of greatest importance. The fork-ends should be in line with the wiring lugs, to which they are connected, or the connecting pins will not be bedding throughout their length. The split pin securing the connecting pin should be in position and properly opened. The thread of the bracing wire should be engaged just beyond the inspection hole in the fork-end, and not so much beyond as will cause fouling on the fitting. When a bracing wire is finally adjusted the locknuts should be tightened at each end of the wire.

Tie-rods and streamline wires should always be checked in respect of the identification and inspection stamps. All nuts should be locked by riveting or other approved method.

All metal fittings should have been inspected to the drawing requirements for correctness of material, accuracy of dimensions, angles, pitch of holes, that the correct heat treatments have been carried out, and that there is no evidence of cracks. Too much stress cannot be laid upon the importance of the removal of sharp or raw edges, as many failures have occurred in consequence of cracks developing from the rough edges left on fittings. A typical illustration is shown in Fig. 39.

Bolt heads and nuts should be properly bedded down. High tensile bolts and nuts are now distinguishable by a groove cut around the hexagon, which facilitates inspection of these details in this respect after assembly.

The use of a scriber for marking lines on wood or metal parts should be avoided, as such marking may cause the commencement of a failure.

Whenever a tube or similar structural member is fitted into a socket, that it is properly fitted, pinned, and bedded at the end of the tube must

form a definite inspectional operation. In like manner, liners and similar fitments which are inserted in tubes, spars, or any other hollow structural parts, must be inspected for position.

In conjunction with this inspectional operation, every case of such a fitment must have an individual stamp applied in a manner that it will not be easily defaced. To facilitate this and subsequent inspections, a "sight," or inspection hole or holes, must be provided, as indicated in Fig. 40.

Particular attention should be paid that all fittings are in their correct position, especially fittings which at first sight appear identical with those in other and similar positions, and yet closer examination reveals that there is some slight difference, perhaps only in one dimension.

A component which is built in a jig, as is often the case, should always be checked for alignment after removal from the jig, because after removal it may spring or twist due to the stresses set up during riveting, bolting, or fixing of the details. An aileron, for instance, may be assumed to be satisfactory when in the jig, yet on removal the spar may bow and throw the hinge fittings out of alignment, due to the pull of the ribs, etc., which have been put on and fixed to the spar while in the jig.

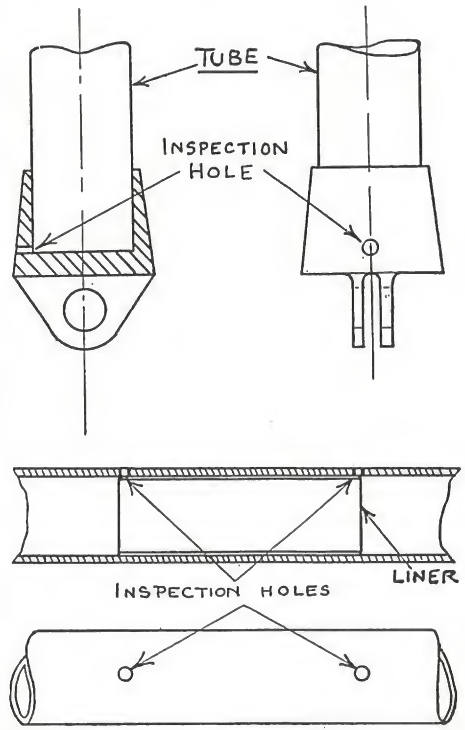


FIG. 40

TRAMMELS

This measuring tool, which is similar in application to a pair of draughtsman's dividers, with the exception that the "points" are adjustably mounted on a beam of wood or metal, is so frequently used in checking components for squareness, etc., that a special description of its use is deemed advisable.

Consider the frame shown in Fig. 41, in which, for illustration purposes, AB and CD are portions of the front and rear spars of a mainplane, while AC and BD are compression struts of equal length at right angles to the parallel spars, and connected by pins at their ends to eye-bolts attached to the spars.

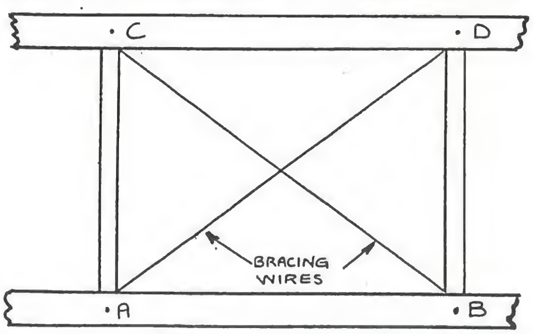


FIG. 41

First tighten the bracing wires until the strain is lightly taken. By

using the trammels, the points A and C are marked off in the centre of the spars and at equal distances from the ends of the respective spars, and approximately on the centre line of the strut AC.

If the plane is so designed that the inner end rib is not square with the spars, that is so far as squareness is concerned, one spar end projects beyond the other, due allowance should be made for this when marking the points A and C.

Point B is marked off on the centre of the spar and approximately on the centre line of the strut BD. Point D should be marked at the intersection of the arcs struck from C with a radius equal to AB and from B with a radius equal to AC. Incidentally, these centre points should be impressed on clip plates attached to the top of the spars, and not on the spars, in order to avoid the possibility of damaging the spar flanges.

The bracing wires should now be adjusted and equally tensioned until the distance AD exactly equals CB, when measured by the trammels. A watch should be kept during any adjustment of the wires that the spars are out of winding. The amount of tension taken by the bracing wires is a matter which is settled by the experience of the operator, but it is needless to say that they should not be over-tensioned, and if under-tensioned, their function will not be fulfilled.

SPLICING OF CABLES

In Fig. 42 is an illustration of an approved type of splice as adopted for control cables.

The use of a thimble inside the cable loop is to prevent the wear of the cable wires, and to avoid the loop becoming deformed when under stress or working conditions.

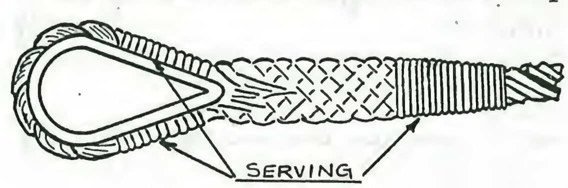


FIG. 42. CABLE SPLICE

The waxed serving on the wire on each side of the thimble is to prevent the cable from unwinding during the splicing operation. The completed splice consists of four and a half tucks. The first three tucks are to be left free of serving, and the waxed thread applied sufficiently to cover the bare end of the wires only.

After splicing and before use, each cable should be proof-loaded to the extent of half the specified minimum breaking load for the size of cable involved.

All completed cables should have an identification tab carrying the part number of the cable, together with the inspector's stamp number.

In order to test the efficiency of the splicer, test specimens should be made spliced at both ends and tested in accordance with the specification requirements.

RIVETING

This process, which is very extensively employed in all parts of aircraft construction, requires the greatest care and attention both during the preparation of the parts for riveting and during the actual riveting operation.

Inspection is facilitated by producing specimen joints representative of the work under inspection, and having these joints sectioned and examined, as the external appearance will not always reveal defective riveting.

Among the essential points to be watched in the riveting process are the following—

1. That the drilling or punching (if authorized) has been satisfactorily carried out, and that the holes are clean and of correct size and pitch.
2. That all burrs are removed from each hole, and all swarf from between the surfaces to be joined.
3. That all rivets are correct to drawing requirements and specifications.
4. That all heads formed in the riveting process are free from cracks and are of the correct shape, definitely securing the work without distortion or damage to the rivets or to the riveted parts. Fig. 43 illustrates a few of the typical defects in riveting.

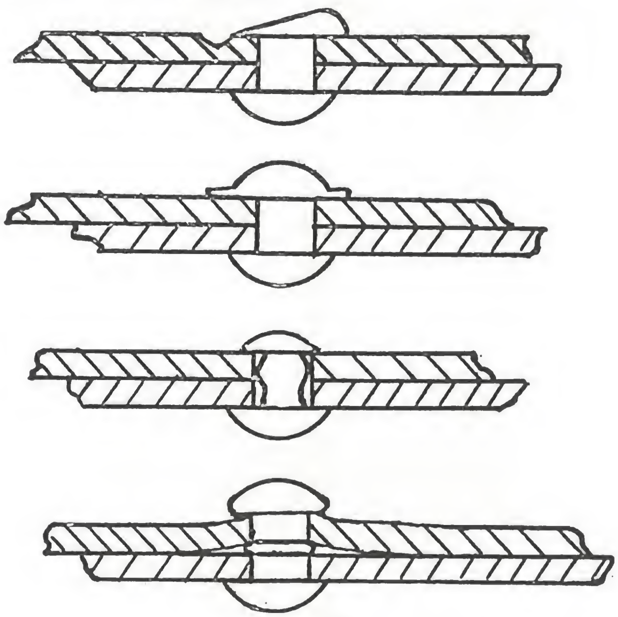


FIG. 43

Snap not struck normally to plate surface—damaged plate and weak head. Rivet too long—damaged plate and rivet. Hole too large—poor head and probable leakage. Plates not held together—deformed shank, weak joint

STREAMLINE WIRES

These wires are rolled by the makers to the required section from a diameter of round wire, which will permit of the ends being screwed to within the limits laid down in the specification. They should always be properly released and provided with a special clip on the streamline portion of the wire on which is impressed the size of the wire and the approved inspection stamp. The presence of this identification clip is highly important, because if it is removed due to any cause whatsoever, and there is no positive evidence that the wire has been satisfactorily inspected, it must be scrapped. Recent practice is to impress size and stamp at the end of the wire, thus avoiding the use of the clip.

At all times when dealing with streamline wires a very careful check should be made that there are no cracks or nicks, because, being of a very high tensile steel, there is every chance of such a crack or nick starting a fracture of the wire.

The above remarks apply in a similar manner to tie-rods, with the exception that these wires are not rolled, but swaged.

TIGHTENING OF NUTS

Too much attention cannot be given to the care required when carrying out the apparently simple operations of tightening nuts, locknuts and threaded parts. The results of either overtightening or undertightening are equally serious. The former may damage or strip the threads, rendering the parts concerned unfit for good service, while the latter results in ill-fitting or badly bedding parts, and possibly leading to a serious breakdown.

B.S. Specification No. 192/1924 and Addenda of May 1927 lays down appropriate lengths of spanners for the various sizes of studs and bolts. The following list selected from this Specification is added for guidance—

Diameter of Bolt	Length of Single-ended Spanner	
	B.S.W.	B.S.F.
$\frac{1}{4}$ in.	5 in.	$3\frac{1}{2}$ in.
$\frac{3}{8}$ in.	6 in.	5 in.
$\frac{1}{2}$ in.	8 in.	6 in.
$\frac{5}{8}$ in.	9 in.	8 in.
$\frac{3}{4}$ in.	10 in.	9 in.
1 in.	15 in.	12 in.

Exception should be taken to the use of ill-fitting spanners and tools generally, in consequence of the damage often caused thereby.

IDENTIFICATION OF RIVETS

The methods of ensuring that rivets of the correct material have been used are various, but the inspector should ensure that any method adopted is foolproof, and should be able to guarantee, for instance, that aluminium rivets have not been used where those of a stronger material are demanded.

For guidance in the cases of light-alloy rivets, those of aluminium could be left uncoloured, while those of alloy variety could each be distinctively coloured by dyeing the anodic film.

Stainless-steel rivets may be distinguished from those of mild steel in that the latter are cadmium-coated. Magnetic qualities will distinguish ferrous and non-ferrous rivets

COMPONENTS

Considering a mainplane of composite construction, that is, a plane of which the chief structural members, such as spars, ribs, etc., are made of timber, and the securing fittings and bracings, etc., are of metal, the remarks regarding the quality of timber detailed in "Non-metallic Materials" at the beginning of this volume are generally applicable to all such components.

For the purposes of inspection, an uncovered main plane is placed with the spars resting on approximately level trestles, and each bay is trammelled in the manner already described, commencing at the attachment ends of the spars. Both spars should be out of winding and straight within the following limits—

A spar having a vertical bow which is smooth and regular throughout the spar length, and at right angles to the plane of the component, may be accepted, provided—

1. That the maximum amount of bow does not exceed $\frac{3}{8}$ in.

2. That only a slight hand pressure applied to the spar is sufficient temporarily to take out the bow.

3. That the bow is such that it will rig out during erection of the component without undue stresses having to be applied during rigging. (By "rigging out" is implied that after erection and rigging the bow must not exceed 1-600th of the length between the points of strut support.)

4. That the timber is not hard-grained or otherwise defective.

A slight horizontal bow in a main spar is permissible, providing it is a regular bow and not due to hard-grained or otherwise defective timber. Further, in consequence of the horizontal bow, no undue stresses are to be imposed on the adjacent details such as ribs and bracing wires. The interchangeability of the component should also remain unaffected.

A spar showing local bowing or twisting in any direction should not be accepted for service.

Ribs must be checked for security of attachments; the crushing of timber members under washers and fittings should be carefully avoided. Adequate clearance must be allowed between bracing wires and rib members, so that no rubbing or chattering takes place. Cases are on record in which bracing wires have been worn at least half-way through due to vibration against wooden rib members.

The aileron hinges should be carefully checked for alignment and positioning. When slats are to be fitted, the attachment fittings should be so positioned that the slats will function satisfactorily in the air, and bed satisfactorily when not in use.

The fittings for attachment of the mainplane to the fuselage or centre-section should be checked against the drawing dimensions.

The principles laid down in this section for the inspection of mainplanes, coupled with the preceding remarks, apply generally to such components as the centre-section, rudder, fin, elevators, and tailplane, with such exceptions as for the limits of bowing of spars, which cannot be allowed on the spars of components carrying hinges for mating with adjacent components. The finer limits required for the alignment and satisfactory functioning of hinges ensure that the spars to which the hinges are fitted cannot be anything but reasonably straight.

All-metal components are also inspected in like manner to the composite components. The question of spar assembly requires special attention to riveting and the ultimate straightness of the spar. The question of any excess limits of bow for all-metal spars, as allowed in the case of wooden spars, must of course receive special consideration, dependent upon the design, that is beyond the ordinary limit of 1-600th, because pulling the bow out of a metal component may set up shear stresses in the rivets.

When dealing with components for an aircraft, any applicable Ground Engineer Notices should be carefully perused.

Before finally stamping as approved, all parts of the component should be satisfactorily protected against corrosion, and in this connection, especially all internal parts, such as the inside of tubes, spars, etc., which should receive an adequate coating.

FUSELAGE

For the purpose of checking the alignment of a fuselage, the component is set up in its normal flying position as shown in Fig. 44, that is, level fore and aft and athwartships, in accordance with particulars given on the drawings.

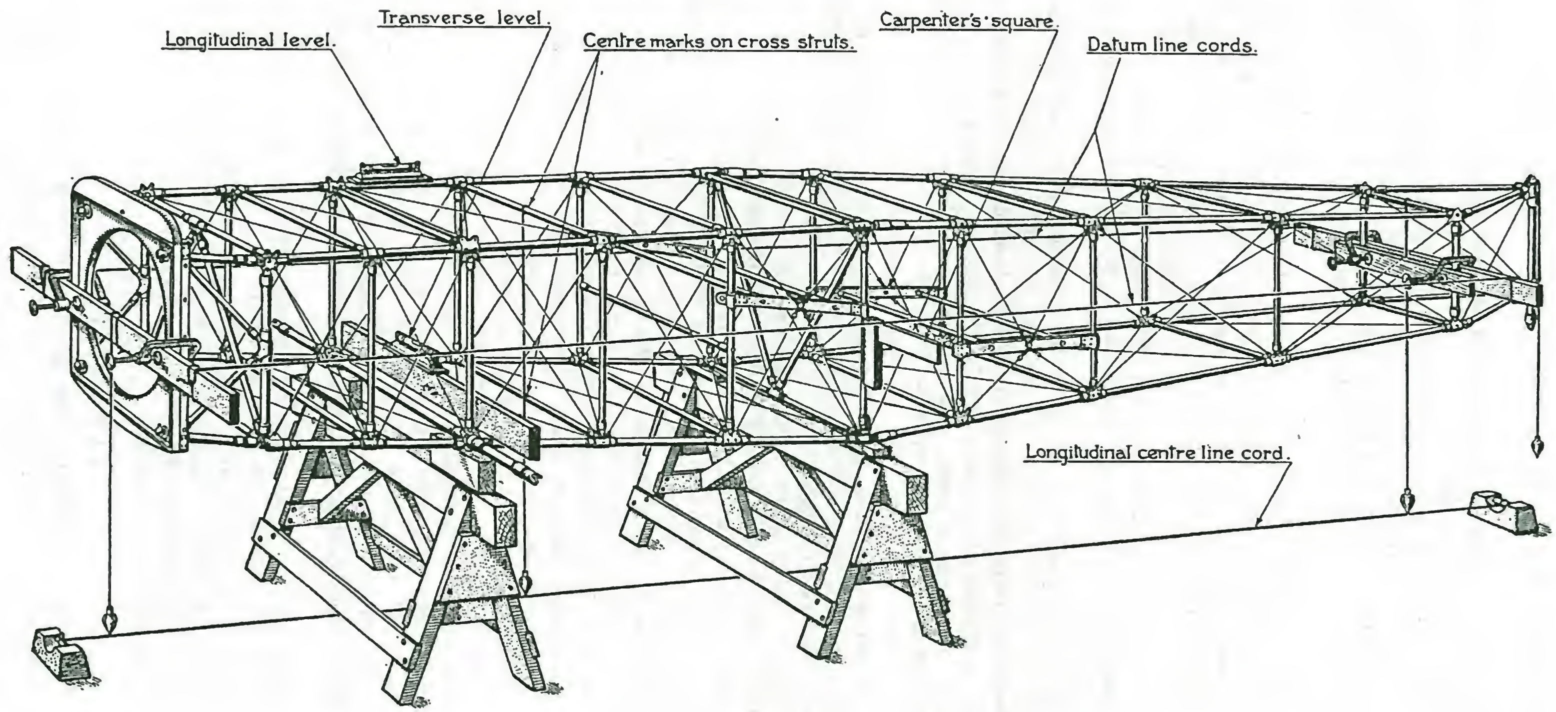


FIG. 44

("Manual of Rigging for Aircraft," by kind permission of the Controller of His Majesty's Stationery Office)

A cord is then attached to two weights and stretched so as to lie just above the floor, and coincident with plumblines dropped from the centre of the foremost top cross strut and the centre of the sternpost. Plumblines similarly dropped from the intermediate top cross struts should coincide with the centres of the bottom cross struts and with the stretched cord. This ensures that the fuselage is symmetrically disposed about its centreline in plan view.

The datum lines are attached symmetrically to the straight-edges at the fore and aft positions as shown in the diagram, and horizontal measurements made at either side of the fuselage should give the same readings at any vertical pair of identical side struts.

For checking that the side panels are correctly disposed measurements are made directly above and below the datum cords, squaring in from the cords where necessary.

All attachment fittings for connecting the fin, tailplane, wings, etc., should be checked while the fuselage is in this position. For instance, a board or straight-edge with suitably designed fittings attached should be tried on to the wing attachment fittings to ensure correct positioning, and that the wings will ultimately engage with the correct angle of incidence.

If the engine to be installed is of the radial type, then the engine bearer plate as shown in the diagram should be checked with the aid of plumblines and using the trammels and the spirit level at appropriate places. For squareness in plan view, diagonal measurements may be made from symmetrical points at each end of the straight-edge to identical points on each side of the fuselage.

In the case of a vertical or Vee-type engine, the bearers on the engine mounting should be checked for position both fore and aft, and athwartships, with the aid of straight-edges, which, when placed one across the aft bearers and one across the front bearers, should be level and out of winding. Similarly, when the straight-edges are placed one on the two port bearers and one on the two starboard bearers, they should again show "out of winding," and level to the designed degree.

Trammels should be used to check the positioning of the bearers with respect to the fuselage.

Inspection should then be carried out on all details and partial assemblies in the manner laid down in the earlier part of this section.

AIRSCREWS, WOODEN

Before inspecting an airscrew, definite evidence must be available that the drawing has been approved authorizing the design of the airscrew for use on the particular engine and aircraft for which it is intended.

Previous to the construction of an airscrew, the planking which is to form the laminations should be tested for compliance with the specification quoted on the airscrew drawing, and exact records of the test results obtained on each plank should be kept for future reference.

When the laminations have been cut, they should further be examined for local defects and rejected if unsatisfactory. It facilitates the work of ultimately balancing an airscrew if each lamina is checked for balance, and the heavy end marked so that the laminations, when fixed in the block, have the light and heavy ends arranged alternately.

As pointed out in the applicable timber specifications, a high moisture content is not permissible, as it is likely to cause warping of the blades after shaping, and in addition an excess of moisture affects the glued joints of an airscrew. Casein cements or cold-water glues are now in common use

for airscrew construction. Cake or jelly glues (that is "hot" glues) are not now extensively used in the manufacture of wooden airscrews, and are not recommended for use when the airscrew is to be used in tropical countries, owing to the possibility of the joints opening in the excessive heat. In the use of any cement or glue, however, it is of extreme impor-

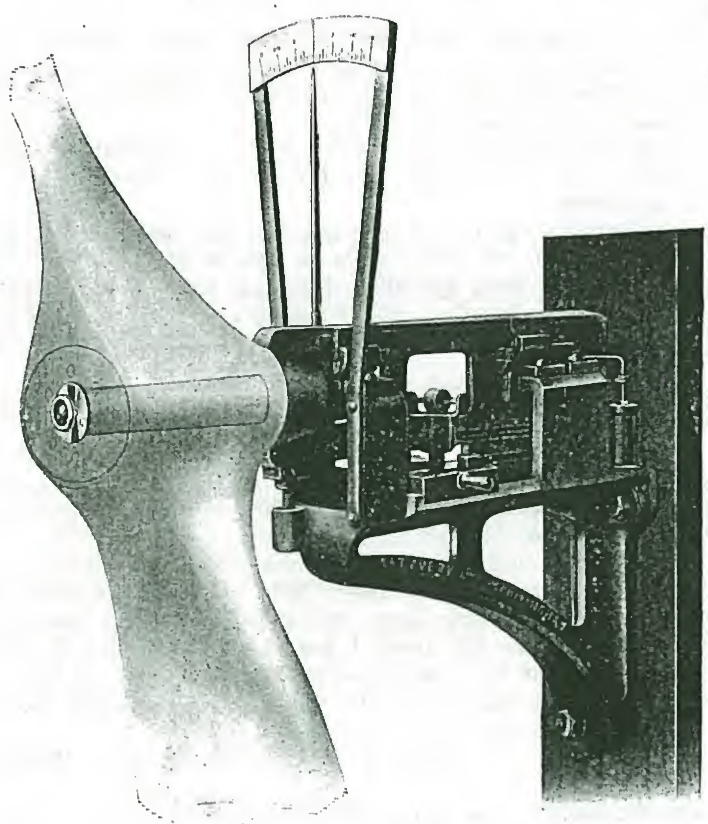


FIG. 45
(By courtesy of W. & T. Avery, Ltd.)

tance that the makers' instructions regarding the application are strictly adhered to.

Strict observance should be made of the prescribed waiting periods between the gluing of the different laminae, and between gluing and rough and final shaping. The actual waiting periods must be carefully recorded on the airscrew record label. When the airscrew has been finally shaped, it must be checked for balance in all positions and must be in static balance in any of these positions, including "vertical balance." Fig. 45 shows a suitable balancing machine. The balancing apparatus must be accurate to within 4 in. ounces when fully loaded.

The limits stated on the drawing for dimensions must be worked to during the construction of the airscrew, but in the absence of such limits the undermentioned may be followed—

> Angles: + or − $1°$ over inner third of blade length; + or − $\frac{1}{2}°$ over outer $\frac{2}{3}$ of blade length.

Chord width: + or – ·03 in., increasing by ·01 in. per inch of the chord over 2 in.
Maximum thickness: + or – ·02 in. for thicknesses up to ·49 in., increasing by + or – ·01 in. per $\frac{1}{2}$ in. of thickness above $\frac{1}{2}$ in.
Diameter: + or – ·25 in.
Track: The maximum permissible error in track dimensions is + or – ·03 in. for airscrews up to 5 ft. diameter, increasing by + or – ·01 in. for every 2 ft. increase of diameter.

In like manner, if no limits are laid down for the boss, bore and bolt holes, the following general limits may be worked to—

Bore: – 0 mm. to + ·5 mm.
Bolt holes: + 2 mm. to + 2·5 mm. on the nominal diameter of the bolt.
Position of bolt holes to be within ·5 mm. of drawing requirements.
Distances between boss faces: + or – 2 mm.
Diameter of boss: + or – 3 mm.

The necessary protective covering and sheaths should be applied in the manner prescribed in the drawing. In the completed stage, additional measurements should be taken to those taken in the white, in order to ensure that the later stages of manufacture have not caused the airscrew to warp or cast. The airscrew should be finally balanced in its finished state. The marking on the airscrew should be in accordance with the particulars on the drawing. All airscrews should be inspected and stamped at definite stages of the construction. These stages are as follows—

1. Physical tests on timber.
2. Moisture content tests.
3. Shop storage of thicknessed boards.
4. Cement tests.
5. Laminations.
6. Mixing and application of cement.
7. Clamping periods.
8. Waiting period before rough shaping.
9. Hand of block.

1st Inspection Stamp.

Correctness of dimensions—

1. Waiting period before final shaping.
2. Balance.
3. Pitch angles.
4. Aerofoil sections.
5. Blade widths.
6. Blade thickness.
7. Boss dimensions and parallelism of faces.
8. Bore diameter.
9. Plan form and alignment of blades.
10. Track.
11. Size of bolt holes.
12. Position of bolt holes.

2nd Inspection Stamp.

Completed airscrew, including tests—

1. Protective covering.
2. Metal sheathing.

3. Filling, varnishing, painting, and general finish.
4. Final check of dimensions, including fitting of hub.
5. Marking (serial and drawing numbers, diameter, pitch, and type of engine).
6. Final balance.

3rd Inspection Stamp.

Repaired Airscrews

The re-sheathing of an airscrew is permissible, providing that the screws and rivets bite into fresh timber. A rubbing should be taken of the old holes in the blades to ensure that the new holes for the screws and rivets are at least $\frac{1}{4}$ in. away from the existing holes.

In the case of airscrews which are subsequently repaired, an additional inspection stamp is necessary, giving an impression of the letter "R" and two numbers indicating the month and year during which the repair is carried out.

AIRSCREWS (METAL)

For the purpose of outlining the principles of metal airscrew inspection, the procedure adopted for the Fairey Reed airscrew is selected, as many of these principles will apply to a variety of types.

The Fairey Reed airscrew is made from thick duralumin sheet, and after being machined to the required shape, the blades are twisted to give the necessary pitch angles. The bosses are formed either of laminated oak or hollow aluminium castings bolted in two halves to the blades.

With the assurance of the requisite design approval, the Ground Engineer should satisfy himself regarding the materials used in construction, heat-treatments, and that all intermediate inspectional operations have been carried out and recorded.

Test specimens should be cut from the blank and carefully correlated during the initial shaping. After initial shaping, but before and for the purpose of the main twisting operation, the blanks should be heated to a temperature of 410° C. After the main twisting operation has been completed, only a slight adjustment of blade angles is permitted in the cold condition.

The blanks are then normalized at the correct temperatures and records made of the temperatures and soaking periods. Final straightening should be carried out as soon as possible after normalizing.

All test specimens should be heat-treated with the blanks and tested after ageing.

Examination for material defects should be made at all suitable stages of manufacture, to avoid the performance of unnecessary work on defective blanks.

All burrs and sharp edges should be removed after boring and drilling to avoid the possibility of the development of cracks resulting therefrom.

The bosses should be so marked with respect to their positions on the blade as to ensure correct re-assembly on any subsequent occasion.

The degree of balance and the method of balancing will be laid down in the specification or drawing, which conditions should be carefully observed.

The following sequence of operations and inspections should be carried out, and recorded before the final inspection stamp is applied—

Identification of material.
Shaping and checking of machined blank for profile, etc.
Correlating test pieces.

Nicked fracture test.
Examination for defects in material.
Heat-Treatment.
Twisting.
Normalizing.

After normalizing, blanks straightened to correct distortion caused by heat-treatment.

Proof tests of aged specimens.
Bedding of hub bosses.
Marking of hub bosses to ensure correct assembly.
Boring and drilling of bolt holes and checking correctness of these operations.
Dismantling for cleaning and radiusing of holes.
Re-assembly and preliminary balance.
Dimensional inspection.
Protective treatment.
Examination of surface for finish and defects.
Re-assembly of hub and final balance.
Identification marking.
Inspection stamp impressed or engraved for final inspection of complete airscrew.
Final stamp, for acceptance of complete airscrew for service.

All checks for dimensions, pitch angles, track, etc., should be made not less than seven days after normalizing, as within this period any of these factors may change.

Repair or reconditioning of this type of airscrew is permissible providing there are no jagged edges or cracks, and any bends are not abrupt. Further, that softening and normalizing are carried out appropriately before and after any straightening or bending.

A letter R should be impressed adjacent to the necessary additional inspection stamp, to identify the airscrew with repair or reconditioning.

UNDERCARRIAGE

This unit is not generally inspected in its built-up form until assembled to the fuselage, unless it is to be held as a spare, in which case it should be assembled to a jig, carrying attachment fittings representative of that part of the fuselage on which the undercarriage is mounted.

In dealing with the partial assemblies of an undercarriage the axle or axles (if it be of the split or divided axle type) are subjected to proof loads by the tube makers before delivery. Axle tubing is of a very high grade steel, and its mechanical properties may be seriously impaired, or cracks started, by the application of heat during any of the subsequent operations after delivery. The temperature during any soldering which may be necessary should never be taken above 200° C.

An inspectional test for cracks in axle tubing may be carried out by washing in paraffin and wiping dry, and covering the tube with a layer of French chalk, when, if there are cracks, they will become evident by the oozing of the paraffin.

All fitments made to the axle should be properly bedded down and have no tendency to impose undue local stresses. The gauge and diameter of an axle must always be checked before final approval.

When oleo legs are used, they should be tested for leaking and freedom of the operation of the moving parts. The open and closed lengths, together with the particulars of loading when closed, will be found on the drawing, and in this respect every leg must be tested for compliance therewith.

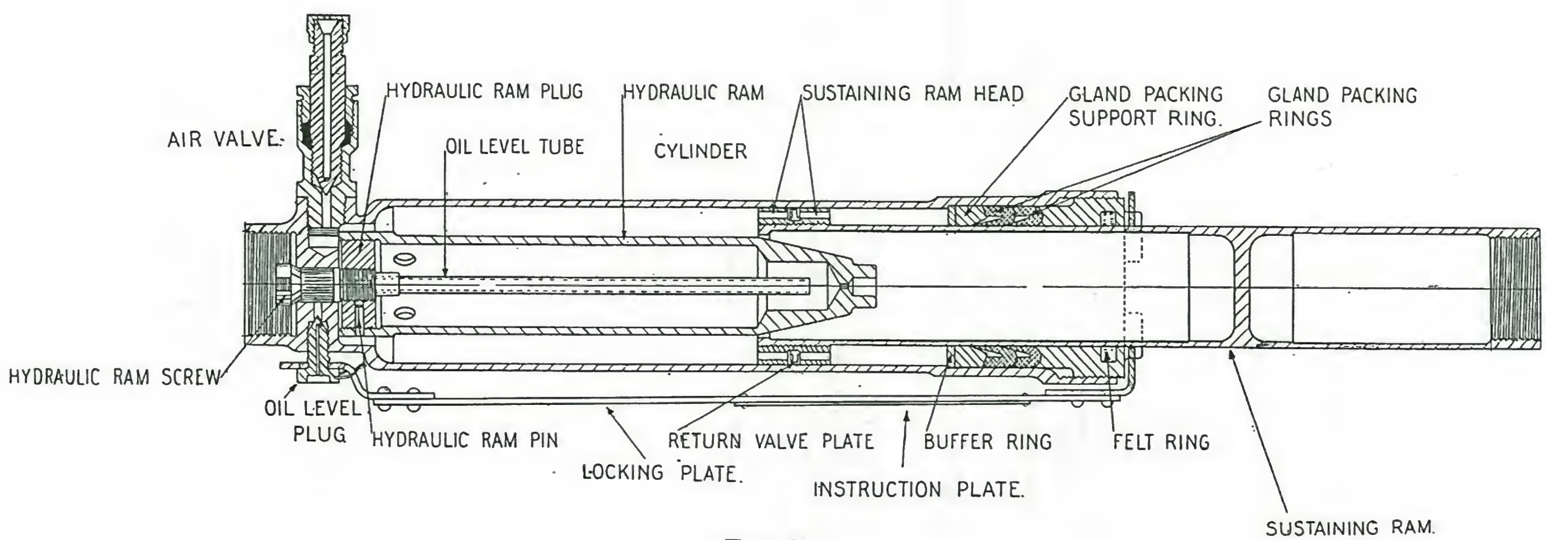

AIR VALVE.
HYDRAULIC RAM PLUG
OIL LEVEL TUBE
HYDRAULIC RAM
CYLINDER
SUSTAINING RAM HEAD
GLAND PACKING SUPPORT RING.
GLAND PACKING RINGS
HYDRAULIC RAM SCREW
OIL LEVEL PLUG
HYDRAULIC RAM PIN
LOCKING PLATE.
RETURN VALVE PLATE
INSTRUCTION PLATE.
BUFFER RING
FELT RING
SUSTAINING RAM.

FIG. 45A

OLEO LEGS

Oleo legs are of various types, but the majority are dependent for functioning on air and oil under pressure. There are also types which, in addition to the oleo portion of the strut, have steel or rubber springing arrangements. Hereunder will be found a brief description of the construction and functioning of the Vickers Ltd. Oleo-pneumatic shock-absorber struts, which are standard fitments on many types of aircraft. On reference to Fig. 45A it will be seen that this type of strut consists essentially of an air cylinder and a piston, the working gland between the piston and the cylinder being oil-sealed to prevent air leakage. The compressed air forms the springing medium, and there is an internal oil brake and rebound damper which dissipates the energy of landing and damps out oscillations.

The air pressure suitable for any particular type of aircraft may be determined by calculation when the load on the strut under static conditions is known. This is checked by the behaviour of the piston when taxying tests are being carried out. If the pressure is too low, the piston will move in too far, causing the machine to roll laterally, while if the pressure is too high, the undercarriage will be harsh and unyielding.

The machine should always be jacked up with its wheels clear of the ground before any adjustments are made to air pressure or oil level. The important requirements on the instruction plate should always be carefully observed if satisfactory functioning is to be obtained.

Air pressure may be supplied by a pump at a pressure of 800 lbs. per sq. inch, or from a compressed air bottle.

Oil level may be checked by releasing the oil valve up to half a turn and allowing the excess oil to blow off. If only air escapes, a low oil level is indicated, and a fresh supply of oil should be pumped into the strut. This check should be made preferably with the air pressure not lower than 100 lb./sq. in. and should never be carried out immediately after flight while the air and oil are in the form of an emulsion.

In describing the functioning of this type of oleo strut there are two movements of the piston to consider. Firstly the upward movement which occurs when the weight of the aircraft is taken in landing, and secondly, the downward and outward movement when the machine becomes air borne and all external load removed from the strut.

Reference to Fig. 45B will make clear the internal operations during these two movements.

As the piston is forced inwards, the oil is forcibly ejected between the Hydraulic Ram and the piston into the air cylinder. The velocity of the oil through this relatively small area is very great, and gives rise to a high pressure in the chamber with a resultant retarding effect on the piston. The oil brake converts the excess energy of the landing into heat. This heat appears in the oil, and is immediately dissipated by radiation from the exterior of the oleo strut.

The outward movement of the piston is controlled by an oil dashpot in the following manner. It will be noted that as the piston moves inwards, oil flows freely into the annular space between the piston head and the lower part of the cylinder, by way of the holes in the piston head and around the plate valve which is suspended in the piston head.

This plate valve closes and traps the oil as the piston moves on its outward travel so that the rate of return of the piston is controlled by the oil passing back, through a small hole in the plate valve, to the air chamber. The return speed of the piston is sufficient to enable the wheels to meet the recurring shocks in taxying, but not sufficiently great to cause bouncing.

As a guide that the oleo strut is in a satisfactory working condition when installed on the aircraft, it is usual to paint a coloured band on the strut fairing indicating the partially closed position of the strut when taking its machine load under static conditions. If the strut closes beyond this position, it is a clear indication that something is wrong.

Regarding inspection, the accuracy with which the detail parts are machined and fitted is of great importance. Adherence to the drawing

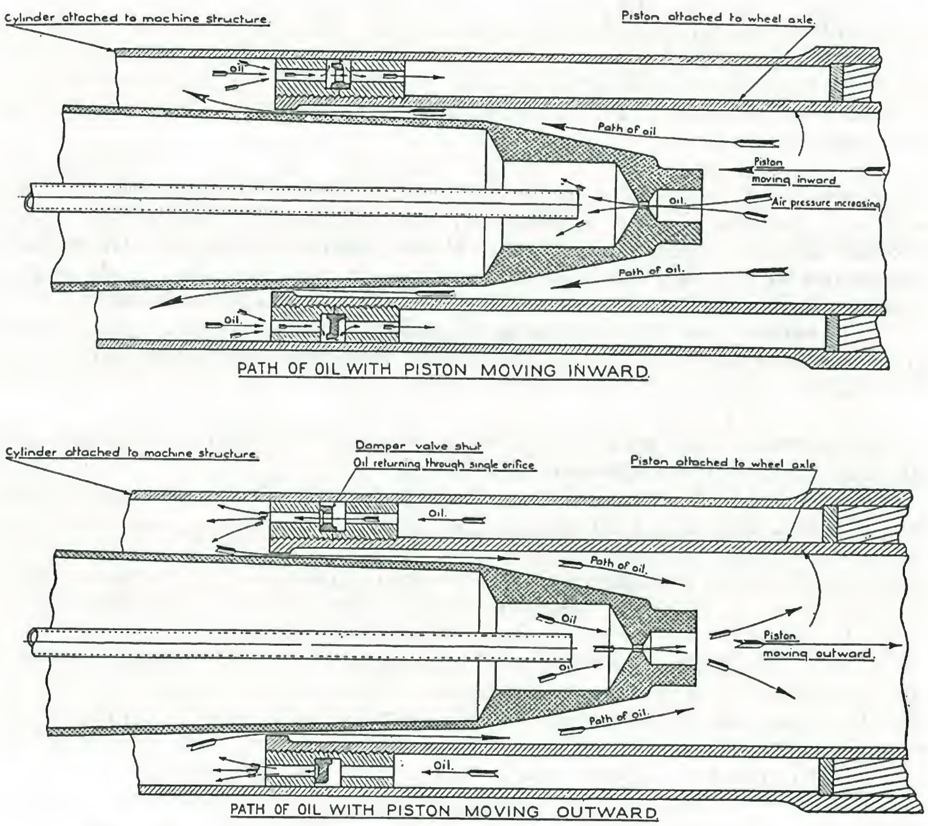


FIG. 45B. DIAGRAMS SHOWING PATH OF OIL DURING TRAVEL

limits should be carefully maintained, as any departure therefrom may cause a breakdown after assembly, together with the lengthy job of dismantling.

After assembly the strut should be pressure-tested in its completed state, and checked to ensure that the moving parts have not distorted due to the application of pressure, special attention being paid to the diameter of the sustaining ram, distortion of which would cause unsatisfactory functioning.

When streamline wires are used for bracing they should be re-examined for condition, notwithstanding that they carry evidence of normal inspection, because of the extremely important function they fill in the landing of the aircraft.

Straining cable is frequently used, and when made up for attachment to the end anchorage, is bent round a thimble to form an eye. The remaining portion of the doubled-over cable is then bound on to the cable itself

with bands of approved wire spaced at intervals as indicated on the drawing. The binding and the intervening portions of the cable forming the complete splice should then be soldered, with every care that the soldering is efficiently carried out. The cable so made up should stand up to 100 per cent of the strength of the unspliced cable.

Rubber is applied in various forms as a shock-absorbing device for undercarriage legs, and the method of determining its length of serviceable life is that of careful periodic examination, during which measurements

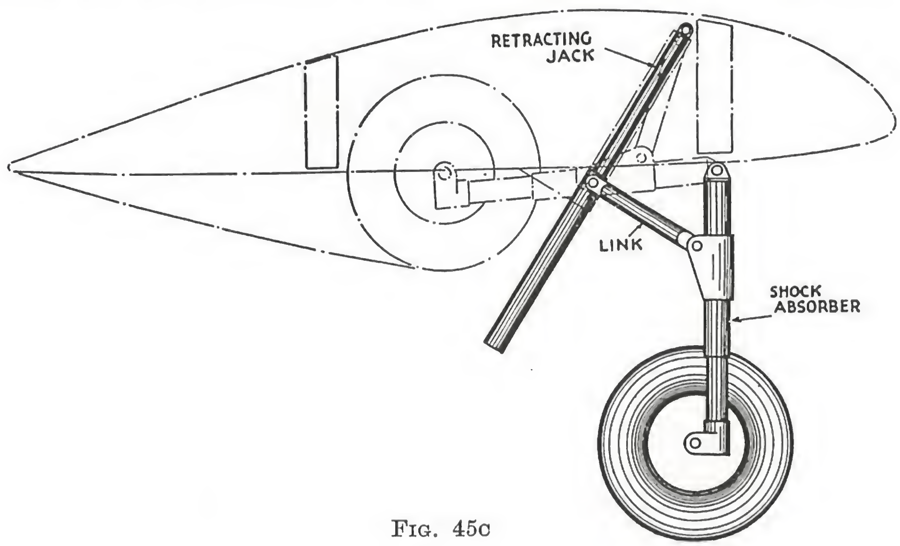


FIG. 45C

should be taken checking the necessary dimensions in the loaded and unloaded conditions.

Landing wheels are always of a specified size and type, and any substitution should only be made after the necessary design authority has been obtained.

RETRACTABLE UNDERCARRIAGES

This type of landing gear is now embodied in the design of quite a number of modern aircraft, and while it improves the speed performance of these aircraft, it adds to the responsibilities of the Ground Engineer.

Fig. 45C illustrates one type of the Dowty retracting unit as manufactured by Aircraft Components Ltd., while Figs. 45D and 45E show views of the Dowty Patent "Nutcracker" Strut for undercarriage retraction as made by the same firm. With the former, when operating, the landing wheel moves rearwards in a fore and aft line to its retracted position, indicated by chain lines, while in the latter, the wheel moves inwards athwartships to its retracted position (Fig. 45E), and can be arranged to embed completely in the under part of the fuselage, reducing drag to a still further extent. These particular units are operated hydraulically by hand or power. Hydraulically operated locks may be incorporated to hold the undercarriage in all intermediate positions, thereby preventing a collapse of the unit if a landing be made with the locking gear not right "home."

A particularly interesting type of hydraulically operated retractable undercarriage is that used on the "Ensign" type of aircraft (Armstrong Whitworth), in which the Lockheed hydraulic system is incorporated.

Fig. 45F shows the undercarriage in the down position, while Fig. 45G shows the up or retracted position. This component normally functions by the pilot using a lever operating a selector valve, which applies hydraulic pressure to the undercarriage jacks. In case of emergency,

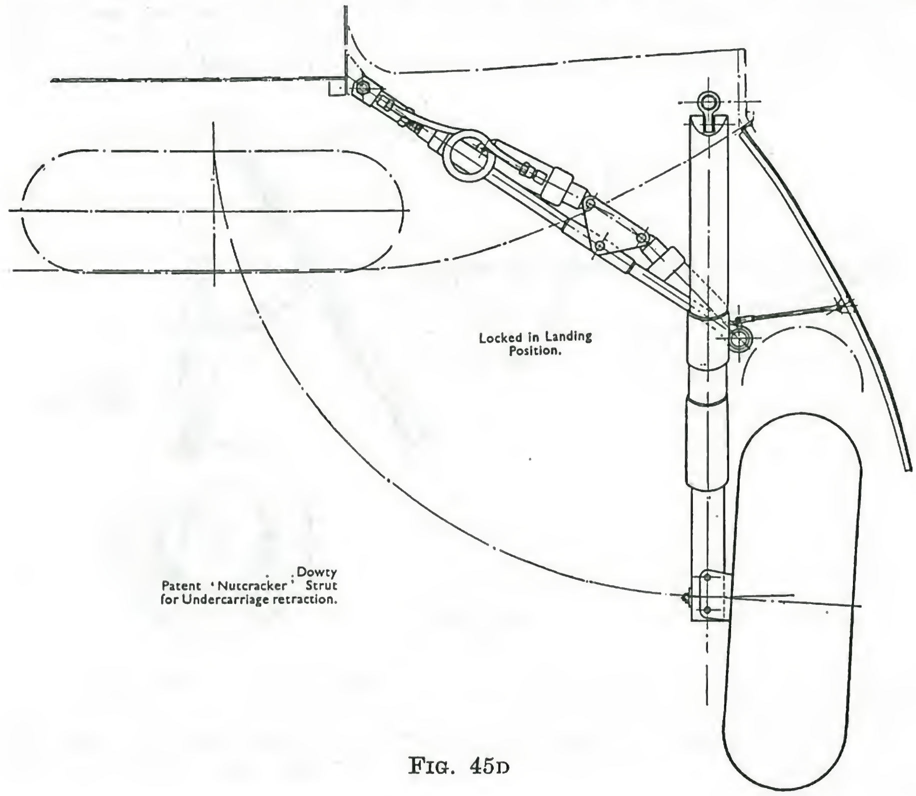


FIG. 45D

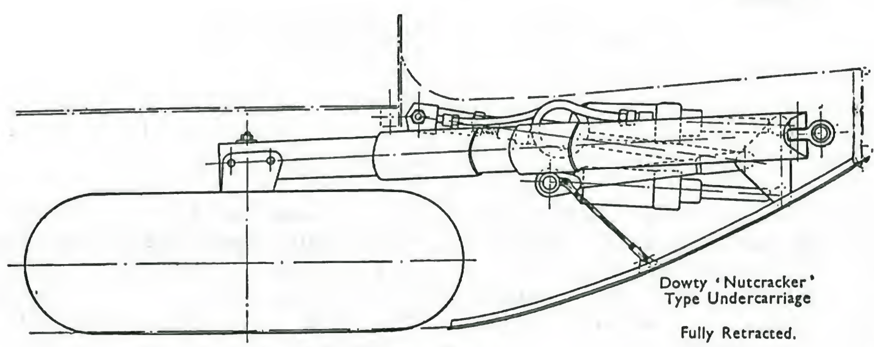


FIG. 45E

that is, if for any reason the pressure fails, the undercarriage may be lowered mechanically by a hand turning device situated in an accessible position in the fuselage.

Whatever type of retracting gear is fitted, after the normal inspection for accuracy of details and assembly, it is essential for the aircraft to be jacked up with the wheels clear of the ground, and the undercarriage retracted a number of times to ensure satisfactory functioning. The pilot's

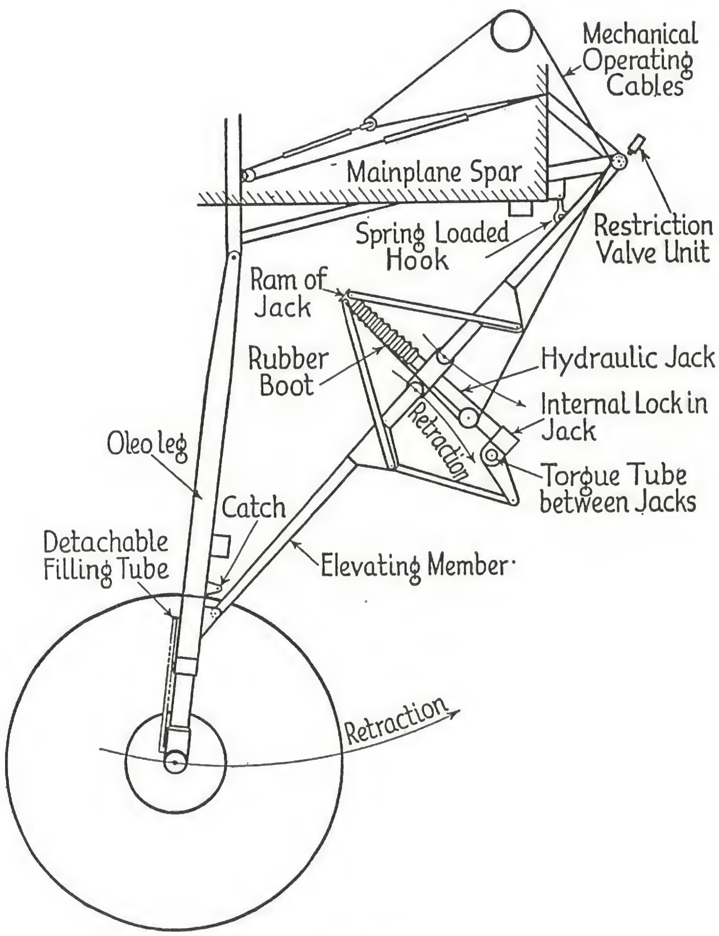


FIG. 45F

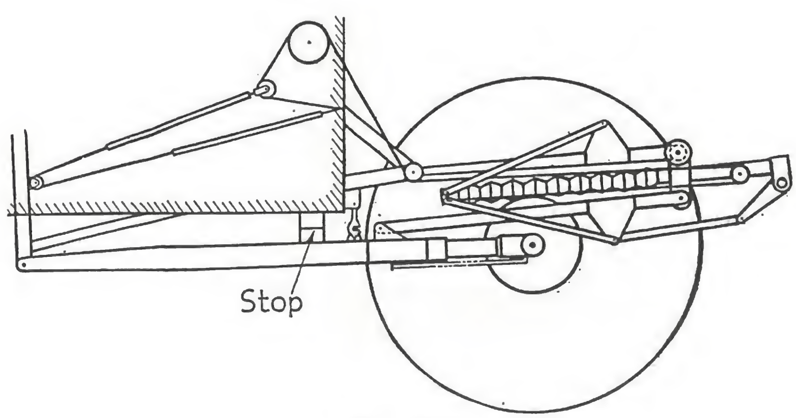


FIG. 45G

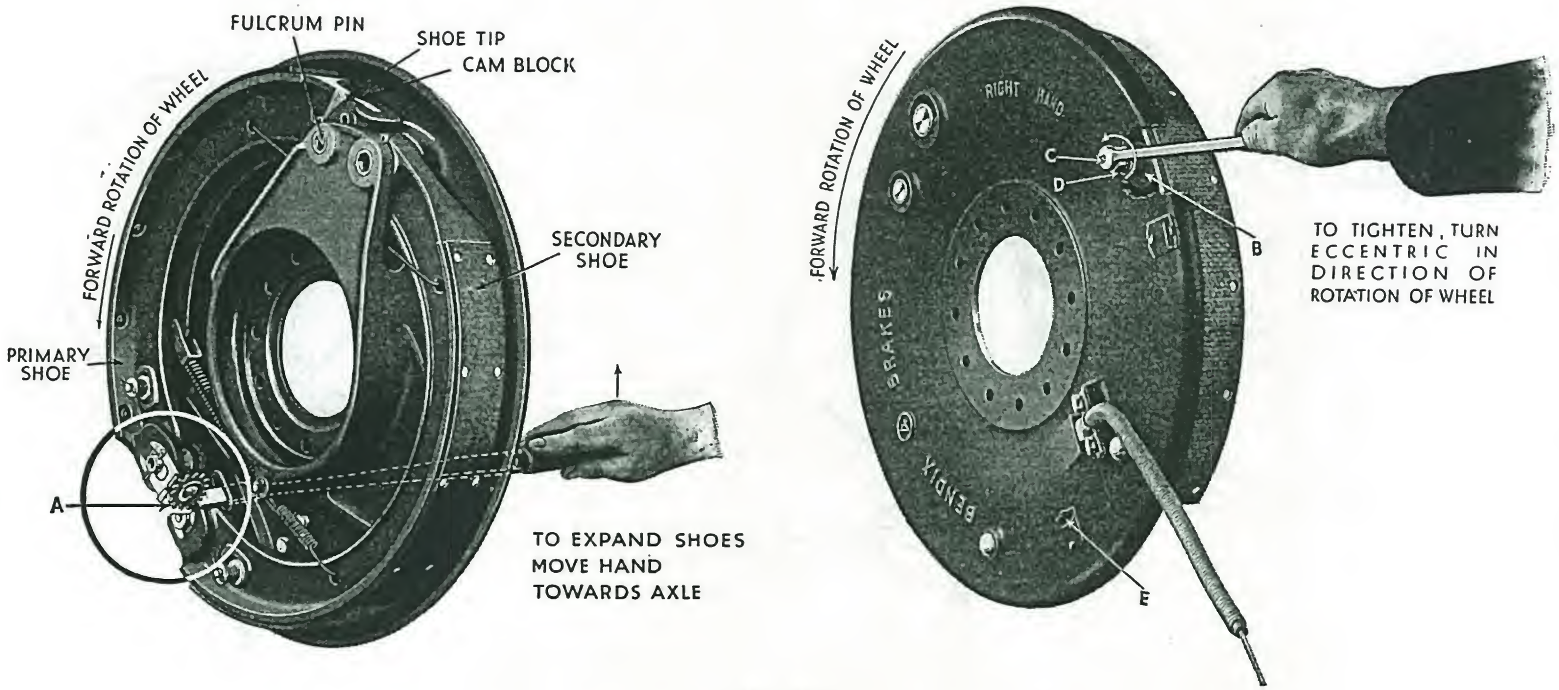


FIG. 46
(By courtesy of Bendix, Ltd.)

warning indicators, showing whether the undercarriage is in the retracted or in the down position, should register correctly during these operations.

If wheel brakes are fitted, the retracting unit should be closely examined while the brakes are being torque tested, to observe specially the nature of the reaction of brake effect on the unit.

The controls should be positive in movement, easy in action, and it should not be possible for them to be put into operation accidentally.

BRAKES

Wheel brakes are now being used on various types of aircraft. Three different kinds of brakes are described in the following paragraphs.

The Bendix Aircraft brake consists of two shoes, primary and secondary, which, when the brake is in operation, are expanded against the inner

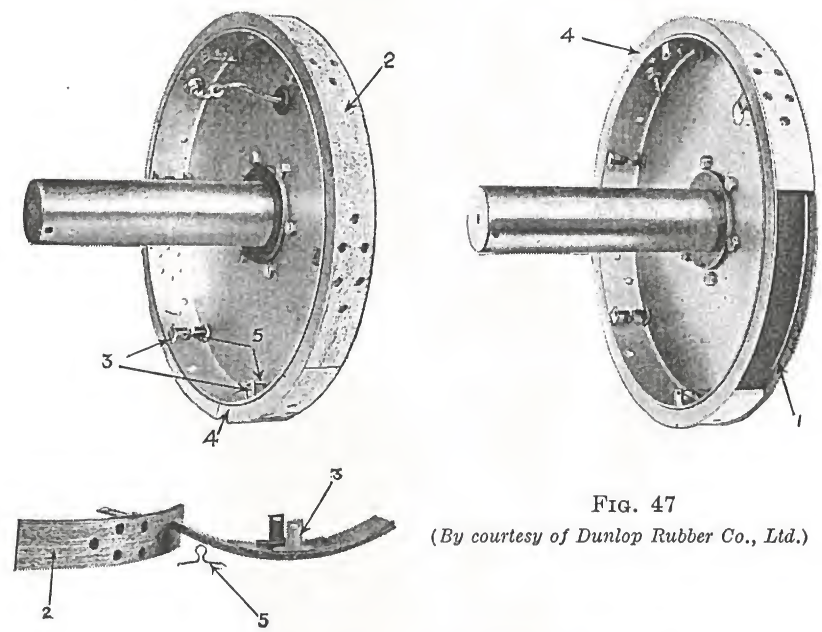


Fig. 47
(By courtesy of Dunlop Rubber Co., Ltd.)

periphery of the brake drum which is attached to and rotates with the aircraft wheel.

The primary shoe is in contact with the cam block of the operating lever at one end, and is hinged at the other to the lower end of the secondary shoe. The other end of the secondary shoe is anchored to the brake back plate.

The hinged connection between the two brake shoes provides a means of adjustment, and consists in effect of a turnbuckle, the inner portion of which is enlarged to form a star wheel *A* (see Fig. 46). When the brake is "off," the cam block on the end of the lever just makes contact with the primary shoe tip when the latter is resting on the fulcrum pin of the operating lever.

To adjust the secondary shoe, move the eccentric *B* in the same direction as that in which the wheel rotates, until the brake just rubs, then ease the eccentric gradually until the drum revolves freely. The primary shoe is then adjusted by means of the star wheel *A* until it just rubs, then slackened off until quite free. Both brakes should be so adjusted as to give the same resistance, for which purpose the brakes should be applied

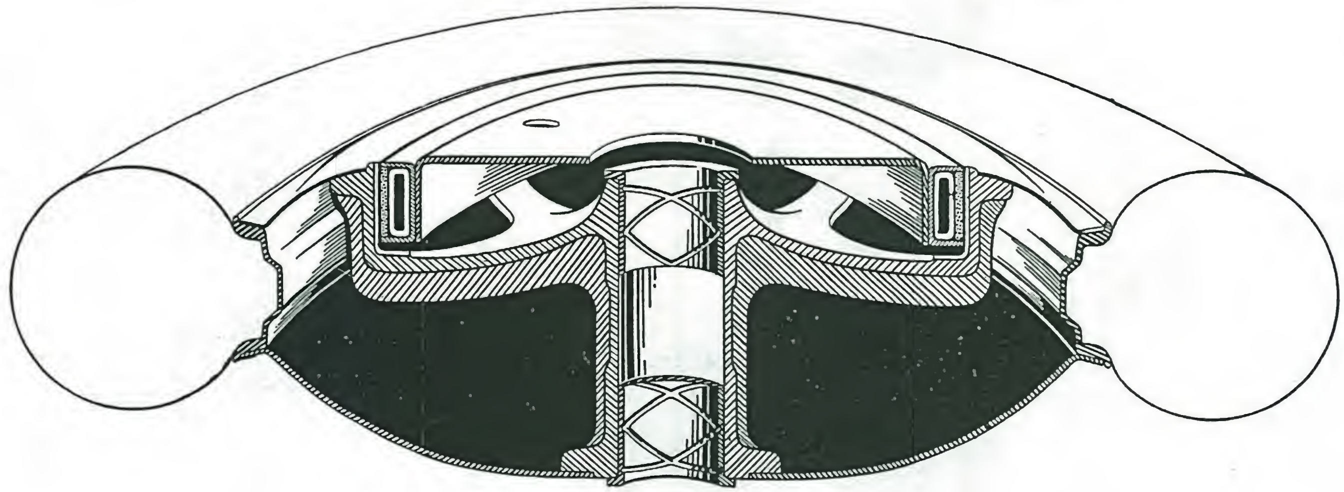


FIG. 48
(By courtesy of Dunlop Rubber Co., Ltd.)

by means of the hand lever or toe pedals. It is considered advisable to replace a complete shoe if relining becomes necessary.

Adjustment for wear on the brake linings should always be carried out by adjusting the brake shoes as already indicated, and never by adjusting the cables.

The operating cables are, of course, adjusted to take up all slack. They should not be so tightly adjusted that they are tensioned, and the adjustment should be the same on each side.

The various working parts are lubricated during the assembly of the brake, and no further lubrication should be necessary between periodic overhauls of the machine, except in the case of cables, for which a special grease-gun is supplied.

Whenever the cables are lubricated, the wheels of the aircraft should be removed so as to ensure that whatever grease is forced out of the end of the cable is wiped off and not allowed to get on the shoes. It is also important that no grease is allowed to accumulate on the brake linings or the drum.

Dunlop Brake Gear

Fig. 47 shows the details of the Dunlop wheel brake unit. It consists of an annular expansion chamber (1), which, when inflated, presses the brake blocks (2) radially outwards against the brake drum of the wheel. The blocks are prevented from rotating partly by friction between the blocks and the air-bag, and partly by the clips (3) which pass through slots in the annular U-ring (4). The springs (5) positively return the brake blocks to the "off" position when it is desired to release the brake.

In Fig. 48 will be seen a half section of the wheel, including the brake. The distinctly novel dual relay valve ensures differential operation of the brakes by connection to the rudder bar or pedals, although the brakes are entirely controlled by one separate hand lever.

Whilst the rudder control is in the "dead ahead" position, the braking effect is equal on each wheel and the degree of braking can be delicately controlled by the hand lever. The physical effort required to operate this lever is small and can be compared with the pull required to operate a motor-cycle clutch.

As the rudder control is moved to steer the craft to the left or right, the braking effect is steadily increased on the inside and decreased on the outside wheel, until in the extreme position of the rudder the brake is entirely released on the outside and any degree of braking desired by the pilot can be obtained on the inside wheel by the operation of the hand control.

Palmer Aero Brake

The operation of this brake may be either by pneumatic or hydraulic pressure, and in each case there are the numerous optional methods of control. The general principle of the Palmer wheel brake will be understood after studying Figs. 49 and 50, with the added footnotes.

Taking for example the hydraulic type of pedal-operated brake, a layout diagram is shown in Fig. 51. The brakes can be applied by means of two small pumping cylinders which are mounted on the rudder bar in such positions as to allow of easy operation with the toe or heel. Each cylinder is connected with its respective wheel brake, while both are fed from one common adjustable reservoir which may be fitted to any convenient part of the structure.

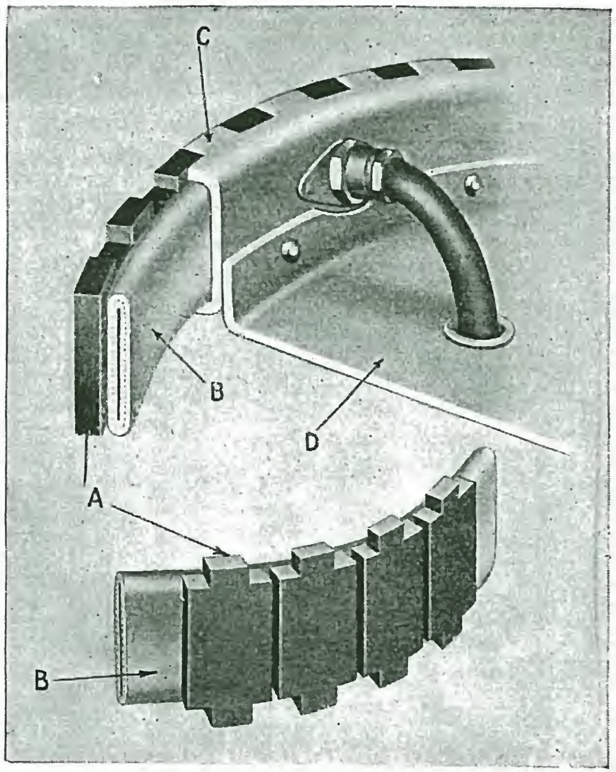


Fig. 49

The brake liner consists of the expansion chamber (*B*) carrying the friction blocks (*A*). The castellated channel (*C*) is attached to the cupped torque disc (*D*). Should the brake blocks become worn they can easily be renewed by removing the brake liner and replacing with a new one

(*By courtesy of Palmer Tyre, Ltd.*)

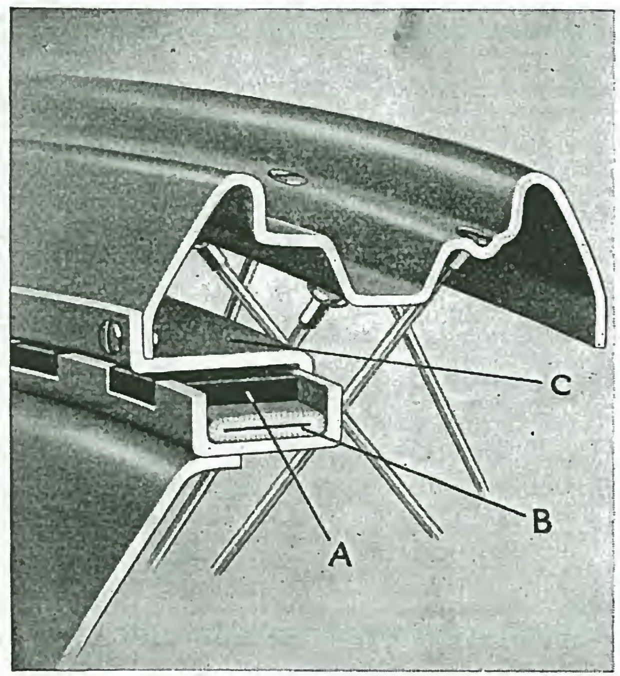


Fig. 50

When air or fluid is forced into the chamber (*B*), this expands and brings the blocks (*A*) into frictional contact with the revolving drum (*C*). The castellated channel prevents the friction blocks from revolving with (*C*)

(*By courtesy of Palmer Tyre, Ltd.*)

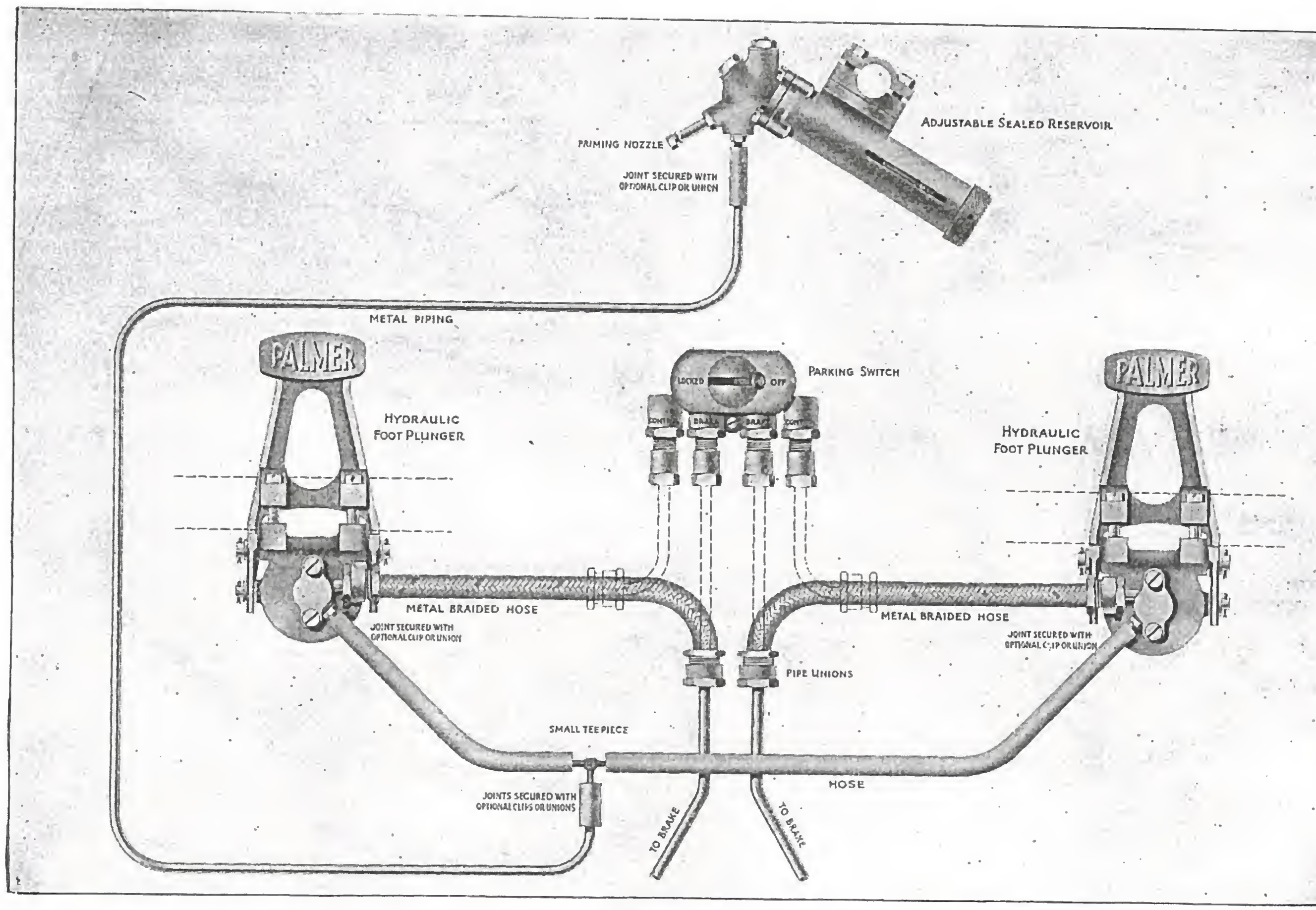


Fig. 51

(By courtesy of Palmer Tyre, Ltd.)

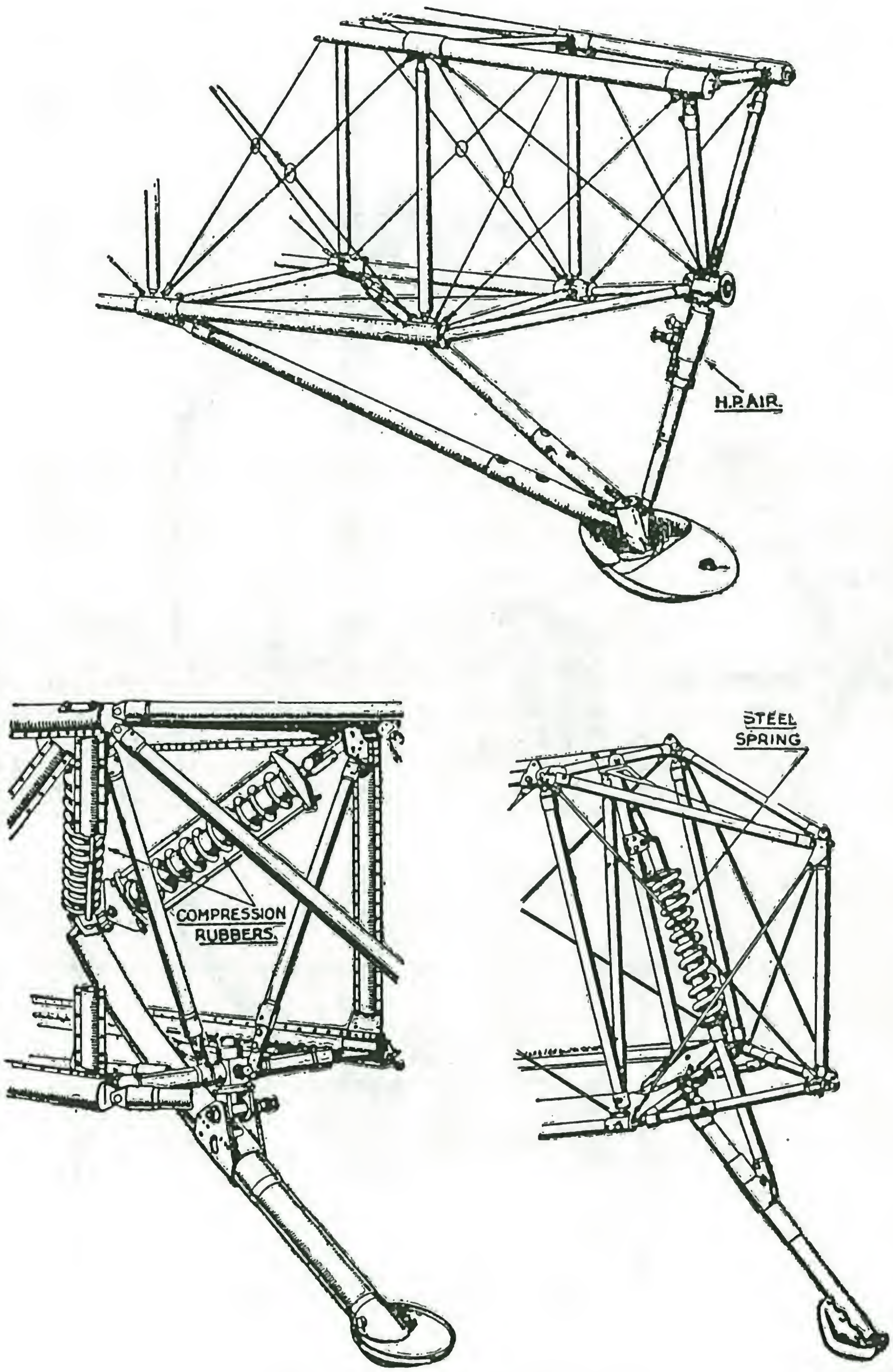


FIG. 51A

The plungers are supplied in pairs, right-handed and left-handed. When priming this system it is essential that the foot-pedals be turned with the nozzles uppermost to ensure that as the fluid is forced in all air will be expelled. If the pedals are left in position they will only be about one-third filled with fluid and the brake will not function.

The method of operation of the parking control is to apply both brakes firmly with the pedals and then switch over the parking control to the "locked" position. This maintains the pressure in the brakes while the pedals remain down after the feet have been removed until such time as the parking switch is turned to "off."

The "parking" switch can be mounted in any convenient place in the cockpit to enable the pilot to lock the brakes in the "on" position when desired.

The action of aircraft brakes should be progressive, and should cease to act on removal of the controlling force. If of the pressure type, the system should be checked for leaks while under pressure. All parts should be inspected in detail, and for final functioning of the brakes a torque test may be applied as described under "Completed Aircraft."

TAIL SKIDS

This component usually consists of the single lever design with steel springs, rubber shock absorbers in compression or tension, or an oleo strut to absorb the shock of the tail landing. Fig. 51A illustrates three different types. A skid shoe of hard-wearing metal, or a tail wheel, is fitted at the lower end of the lever.

The shock-absorbing unit should be independently checked for correct functioning previously to assembly.

If the tail skid has been in service, its parts should be examined for damage, fracture, wear and buckling or bending of tubular members.

INSPECTION OF PETROL, OIL, AND WATER TANKS

All materials used in the construction of tanks must have been properly covered with approved Release Notes, and must comply with the specifications called for on the tank drawing.

Fig. 52 shows a typical joint for connecting the end to the shell of a tinned steel, brass, or copper tank.

With aluminium tanks, it is common practice to weld the joints, and Fig. 53 illustrates the sections of typical joints.

An important stage of inspection is that of a tank submitted before closing the interior by means of the sealing end, and at this stage the whole of the interior of the tank should be carefully inspected. It is important to examine the riveting, that all the sharp edges from baffles, etc., have been removed, and the flanges and fittings at the apertures have been finished off satisfactorily.

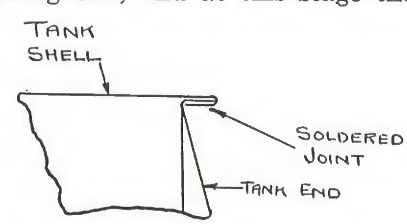


FIG. 52

It is general in aircraft construction to prohibit incisions or such marks as are made by scriber points, and the observation of this ruling is most essential in the construction of tanks.

The pressure test is next carried out at a pressure stated on the drawing, or, failing this, the pressure laid down in the relevant inspection leaflet.

For this purpose a quantity of paraffin, equal to one-tenth capacity of of the tank, is inserted, and all apertures adequately sealed, and the required pressure applied to the tank. While the pressure is still applied, the tank should be moved about in all positions so that in turn the paraffin touches all possible parts of the shell, when, if the tank is not sound, the leak will be easily seen by traces of paraffin on the outside. It assists detection if the joints and all important connections on the tank are coated with some such material as whitening.

An alternative and accurate method of testing a tank up to the requisite pressure when a pressure gauge is not available, is to fill the tank completely with paraffin and apply a head of paraffin equal to the pressure demanded by the drawings. An easy method of applying a head is to drill a hole in a filler cap and fit into it a length of metal tubing of a suitable diameter (say $\frac{1}{2}$ in.) so that the tube is vertical when the filler cap is fitted to the tank inlet. The tube may be cut off to the length required and the paraffin poured into it carefully to avoid any possibility of an air lock. See Fig. 53A.

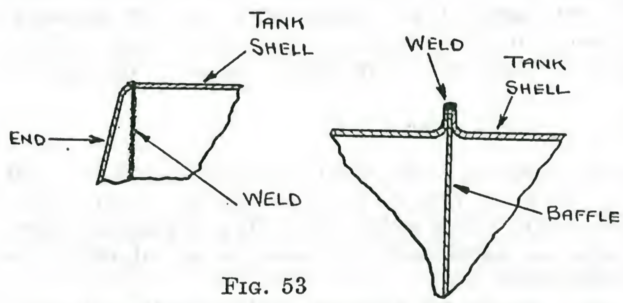


FIG. 53

After the completion of a tank, it must be washed thoroughly with hot water to remove any dirt or foreign matter, and all traces of the soldering flux, which, if allowed to remain, causes rapid corrosion. Such washing must be followed by efficiently drying the tank.

The capacity of a tank carrying more than 10 gal. should be within plus or minus 2 per cent of that specified, and not less than minus 2 per cent of the capacity specified in the case of tanks of under 10 gal.

The capacity marked on oil tanks should always allow for the specified air space. The Design Leaflet lays down that the filler must be so located that sufficient air space is left and an adequate vent provided.

An inspector should not stamp a tank as approved until he is satisfied that all standard rulings have been complied with and that the tank conforms to the applicable drawings and specifications.

DE BERGUE RIVETED TANKS

Many petrol, oil and water tanks are now constructed from light alloys such as duralumin and alclad, in which the joints are formed by the De Bergue Patent Countersunk Riveting process.

Here it should be noted that welding the joints of duralumin and alclad tanks is not an accepted practice, as the temperatures necessary for welding embrittle the metal in the vicinity of the weld to a dangerous extent. Subsequent heat-treatment will not remove the effect of this brittleness.

Initially the joint is formed, and the holes drilled, in a manner similarly to the ordinary riveted joint.

The riveting is performed on a specially designed pneumatic squeeze riveting machine. The gap of the machine is usually arranged vertically, and operated by a treadle so that the operator has the freedom of both hands, for manipulating the jointed plates on the tanks.

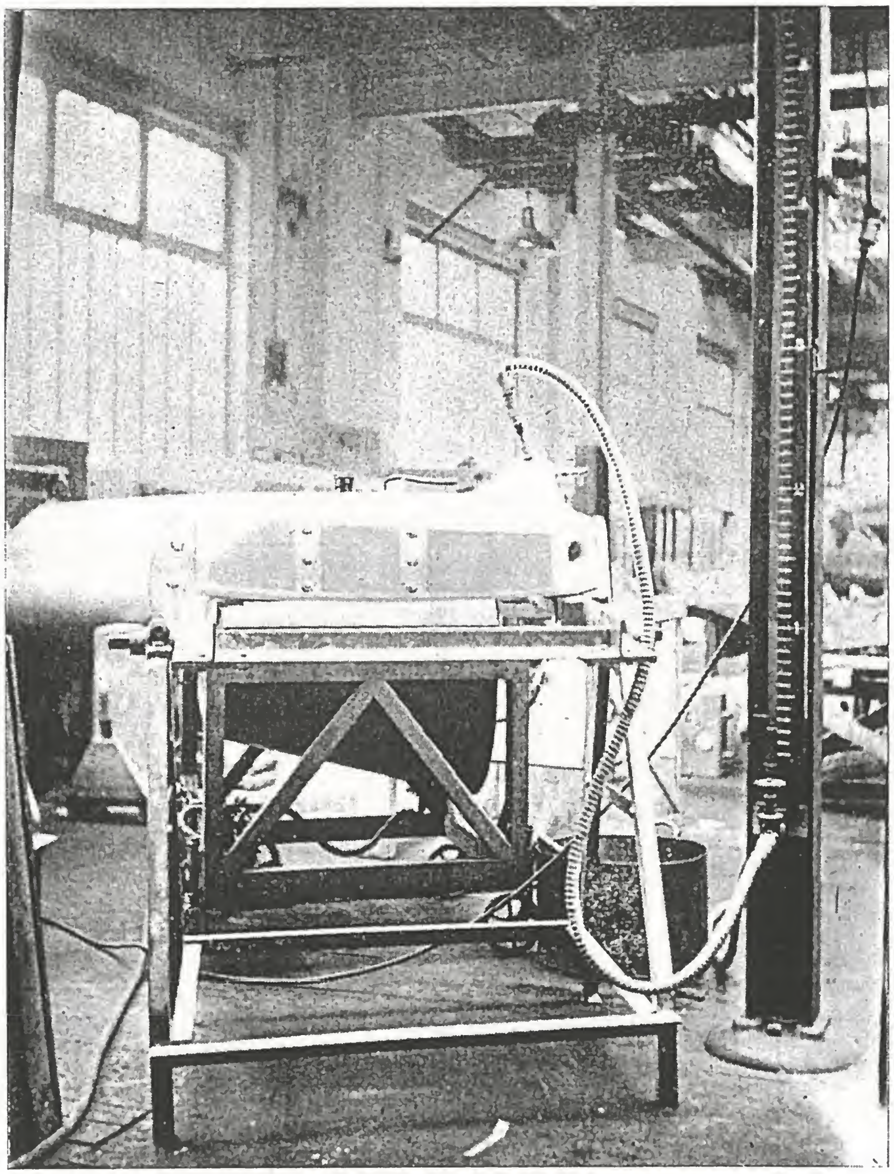


FIG. 53A

Fig. 53B shows a section of part of a joint before and after riveting.

The Jointing material may be thin rubber proofed fabric or any material specially approved for the purpose.

In the case of rivets becoming leaky through the tank being damaged, they may be replaced by new rivets $\frac{1}{32}$ in. larger in shank diameter than the original rivets, but with the same size head as the original rivets.

If re-riveting is impossible through inaccessibility, as in the case of tank baffles fixed to the shell by this process, a screwed bolt suitably washered may be employed. A washer of similar material to that used for the jointing should be employed under the metal washer.

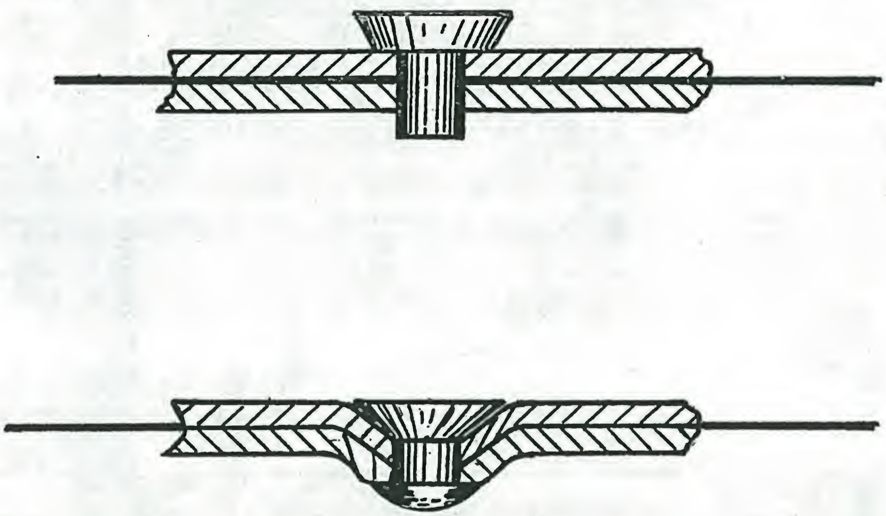


FIG. 53B

The method of examination of tanks constructed by this process follows the usual methods laid down herein.

RADIATORS

Before proceeding with the final inspection of radiators, it is most essential that the processes involved in the manufacture have been carried out satisfactorily.

All soft-solder used in the construction is that known as Grade "B," which has approximately 50 per cent tin and 50 per cent lead, and has a higher melting point than Grade "A" solder, with approximately 65 per cent tin. The melting point of the former is approximately 205° C., and of the latter 180° C. The object of this ruling is that when repairs are afterwards carried out, by using Grade "A" solder there is no risk of affecting soldered joints in the locality of the repair.

All details shall have been inspected and made from approved materials, especially the radiator tubes. These tubes are manufactured from very pure brass of the following composition—

Copper, between 68 and 74 per cent.
Zinc, the remainder.
Impurities—
Lead, not more than ·05 per cent.
Iron, not more than ·05 per cent.
Bismuth, not more than ·006 per cent.
Nickel, not more than ·1 per cent.
Any other metallic impurities (excluding silver), not more than ·005 per cent.

Every tube, while subjected to an internal air pressure of 15 lb. per square inch, is immersed in water and must show no sign of leaking.

In the manufacture of the radiator shell and tankage, a very careful check should be made of the attachment and soldering of all suspension brackets and fittings to ensure that—

(*a*) The radiator is correctly positioned in relation to the ultimate attachment to the aircraft.

(*b*) All rivet and bolt heads on the inner side of the shell have sufficient clearance to obviate the risk of damage to the tube block during "panting" of the casing.

(*c*) All joints and rivets attaching fittings have been cleanly and sufficiently soldered.

Special care should be taken in the use of cramps whilst building the tube block, as due to their thinness the tubes may easily be distorted, and it is essential that a check of dimensions over a number of tubes be made at this stage, as the weight of solder picked up in dipping and the water-tightness of the finished block are directly governed by the spacing of the tubes. During construction all parts should be kept free from dirt or grit, or loose solder, owing to the very narrow waterways in the completed radiator, which so easily become blocked.

Just previously to dipping a tube block it is necessary to ensure that—

1. The tubes are levelled on the block faces on a surface plate.
2. The surface of the solder bath is skimmed to remove any dross, and that the flux bath is clean.
3. The solder bath temperature is correct and pyrometrically controlled.
4. The blocks are sealed to the correct depth on the tube bulges.

The analysis of the solder should be periodically checked in order to maintain consistency of composition.

Great care should be exercised during the "loading" of the casing to the tube block, to ensure that strips of solder do not penetrate beyond the swaging of the casing at the inner end of the tube bulges.

After completion, the radiator shall be tested to ensure that—

1. The dry weight is within the limits specified.
2. The capacity is as shown on the drawing.
3. It will withstand for 10 min. a pressure of 6 lb. per square inch while filled with water at 180° F. without leaking. Immediately following the removal of the hot water, the radiator shall be filled with cold water and subjected to the same pressure as above for not less than 30 min., and again show no sign of leaking.
4. The flow of water through the radiator satisfies specified requirements, while being flow tested under a constant head of 7 ft. of water, which head is measured above the radiator inlet.

The flow is measured by the quantity of water issuing from the radiator outlet. The measuring vessel should not be more than 1 ft. below the radiator outlet. The duration of the test must not be less than 20 sec. after a steady condition of flow is maintained, the time being recorded by means of a stop-watch. During the test, the radiator must be in a position similar to that which it would occupy in the aircraft.

Repairs

Before any repairs are effected on a radiator it is essential that the radiator be emptied and dried. A special degree of skill is required in effecting soldering repairs in the vicinity of the tube block, especially to prevent the ingress of solder, as an overheated soldering iron may unseal a number of tubes. To remove a leaking tube from the block a pair of

punches, which have been shaped to fit the ends of the tube, should be heated and inserted the full depth of the bulges at each end of the damaged tube. When the solder at the end of the bulges becomes fluid, the tube may be carefully pushed out of the block from one side.

If a new tube-block is necessary, after removal of the old block all traces of corrosion and foreign matter must be removed and the casing rendered as new.

In the case of a radiator requiring repair to a tube-block, no plugging of tubes is permitted, and tubes which leak at points other than soldered joints must be replaced.

After repair the necessary tests must be carried out as for new radiators.

OIL COOLERS

With the introduction of modern high-powered aero engines and the necessity of cooling such engines as much as possible, oil cooling by means of a specially designed component became inevitable.

The cooler is usually inserted between the engine scavenge pump and the oil tank, thus cooling the oil to the required degree on its return from the engine to the tank ready for re-delivery to the engine.

These coolers come within the category of aircraft components, and must follow the usual course of inspection both with regard to the details and the finished unit.

There are many different types of oil cooler, but in these pages I shall confine myself to the description and methods of inspection of the Vickers-Potts type.

As will be seen from Fig. 53c it consists of a number of hollow fins threaded on two tubes, and so arranged that the returning oil passes down to the bottom of the inlet tube, thence through each fin in turn to the outlet. Next the outlet will be seen the by-pass valve inserted between the inlet and outlet pipes for relieving the pressure when starting from the cold, and in order to avoid excessive pressures in the fins.

During assembly of the fins on the tubes, it is essential that the embossed "O"'s at one end of each fin appear in the following positions—

Top fin	O on top
Second fin	O on bottom
Third fin	O on top
Fourth fin	O on bottom
Fifth fin	O on top

and so on to the completion of the unit up to a maximum of eleven fins

It is further important before finally tightening the end nuts, that the duralumin spacers are central. The following are outstanding features of inspection in addition to the normal routine inspection—

1. Each fin after completion and inspection should be tested with mineral oil at a minimum temperature of 40° C. at an internal pressure of 45 lb. per square inch. The word "tested" and a covering inspection stamp should be impressed to indicate satisfactory passing.

2. Before assembly and after normal inspection, the relief valve should be tested at an inlet pressure of 15 lb. per square inch, and the word "tested" and the inspection stamp added as for the fins.

3. A flow test on the completed cooler must be carried out with mineral oil at a temperature of not less than 40° C., the oil flowing freely through the cooler. It is important to observe that each fin warms up in correct order to indicate a satisfactory flow and correct assembly of the fins.

4. A pressure of 25 lb. per square inch should be applied while the

(Oil Cooler, Standard, Air Ministry Type A 325)

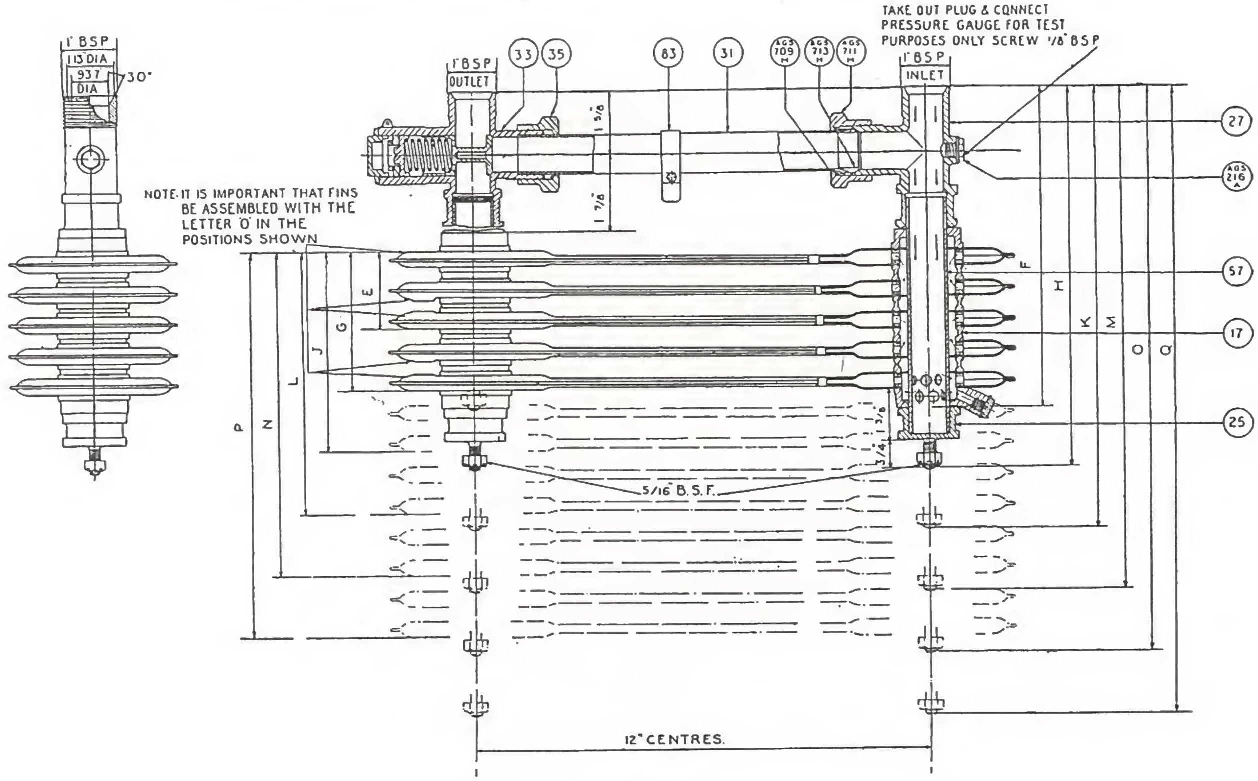


Fig. 53c

cooler is filled with hot oil, and this pressure maintained for fifteen minutes without showing any signs of leakage.

ACCESSORIES FOR PETROL, OIL, AND WATER SYSTEMS

All cocks, valves, pumps, filters, and similar assemblies, should have their detail parts independently examined, and stamped previous to assembly, and the completed article finally stamped as conforming to the drawing. Identification numbers or letters should be impressed, denoting type, etc., to avoid the incorporation of an incorrect article into any system concerned. Before finally testing such parts, they should be cleansed from all grit, solder, and any foreign matter. The writer has knowledge of the forced landing of an aircraft due to a tiny piece of cotton fibre adhering to the seating of a relief valve, and thereby putting the valve out of action. The importance of cleanliness cannot be too heavily stressed.

Testing

The specified tests for flow, pressure, etc., should be carried out on every accessory, on which should be stamped the word "TESTED," providing that they are up to the standard required.

The nature of the tests is usually specified, but in the absence of such specification and for general guidance, all petrol cocks and valves must withstand an internal pressure of 15 lb. per square inch without leakage. This test may be carried out by using paraffin internally, the castings being whitened externally, or by means of air pressure, with the cock or valve immersed in petrol or paraffin.

They should also be flow-tested under a standard head of 1 ft. Each cock or valve, when open, must pass petrol at not less than the minimum rate of gallons per hour called for on the drawing or specification. It is important that only petrol should be used for the flow test, because any other liquid will give an erroneous idea of the rate of flow obtainable.

Drain cocks with a film of oil between the plug and the body must withstand a test pressure of 15 lb. per square inch without leakage. Each petrol pump must be pressure-tested to 15 lb. per square inch and be tested for delivery capacity under conditions of speed and suction, and delivery heads applicable to the particular pump.

CHAPTER IV

HULLS AND FLOATS

So far as the inspection of the flying structure of a float seaplane or of a flying boat is concerned, there is very little difference between this and the inspection of a land-plane.

The hulls and floats, however, involve different methods of inspection, especially in the early stages of construction, and, unlike a number of fuselage designs, do not allow of any readjustment in alignment when completed.

Further, while particular attention is paid to protective processes on land craft, even greater precautions are necessary in the case of sea craft, due to the intensive corrosive action of sea water and sea air, and for this reason such materials as alclad and other aluminium alloys, which are in general use (particularly on account of weight), are anodically treated as a primary protection against corrosion. Stainless steel is used for fittings, etc., but at present is not in general use for shell plating.

Details

All details from which the assembly is made or repaired must be previously inspected for compliance with the drawings, and for the observance of standard rulings with regard to protective processes, etc., and must bear evidence of this inspection.

The inspectional work should be carried out in progressive stages during construction, varying only to suit the particular design or the methods of different constructors. The satisfactory completion of these stages, which are outlined below, should be recorded on a card or chart so that when final inspection takes place, the inspector will have every assurance that previous inspections have been fully carried out.

"Lay-off" of Lines, etc.

Careful checks should be made to ensure that the "lay-off" from the scale drawing to the full size on the mould loft floor has been carried out correctly. The moulds and templates must be checked with the lines and body sections on the mould loft floor and scrieve boards. A scrieve board is one on which the various sections or half sections of a hull or float are drawn out full size, the idea of which may be gathered from Fig. 54.

The contour of each frame is to be checked to the scrieve board, while each section of the keel, keelson, and stem is checked to a profile template on to the lines laid off on the mould loft floor.

The centre and datum lines should be checked while the moulds or frame supports are inspected for position and levels. On the stocks, the assembly of such members should be checked for alignment, location, and security, including their positions relative to the centre and datum lines.

Assembly Inspection

The assembly of the framing should be inspected before the shell-plating is fitted. This stage includes the inspection of all frames for fixing and position, all internal work such as the assembly of all intercostals, ribs, stringers, etc. Levelling and datum brackets should be carefully checked, because on these subsequent alignment so much depends.

Shell-plating (see Figs. 55 and 56)

The watertightness of a hull or float is dependent upon good workmanship, and should be obtained by well-fitting seams and good riveting. The punching of rivet holes is not permitted, but drilling only. A check should be made that all holes are drilled to the correct size and pitch. Burrs should be removed from each hole and all swarf cleaned from between the fitting surfaces, to ensure that the parts come in close contact during the

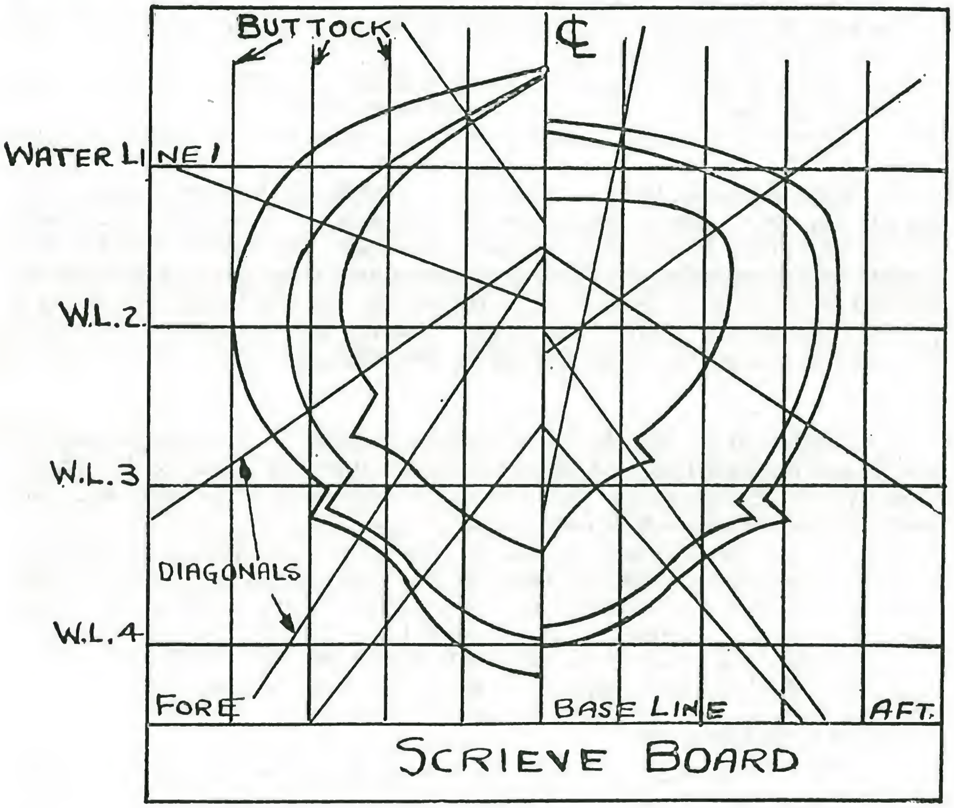


FIG. 54

process of riveting. Correct clearance should be allowed between the rivet and hole. The drifting of holes is prohibited.

All contact faces of seams and all other joints are coated with an approved jointing medium, such as a liquid marine glue, or enamel; the object of this coating being not only to provide an additional safeguard against leakage, but also a further protective coating against corrosion. The use of stopping is deprecated, and should only be used in positions such as where longitudinal and vertical seams meet, and it is difficult to make a satisfactory tight joggle.

All plating requiring anodic treatment should have this process carried out after all work, including the drilling of rivet holes, is completed, which will involve dismantling after temporarily fitting the plating.

Final Inspection

Before final inspection for alignment, which follows closely that laid down for the fuselage of a landcraft, the hull or float is to be freed from all

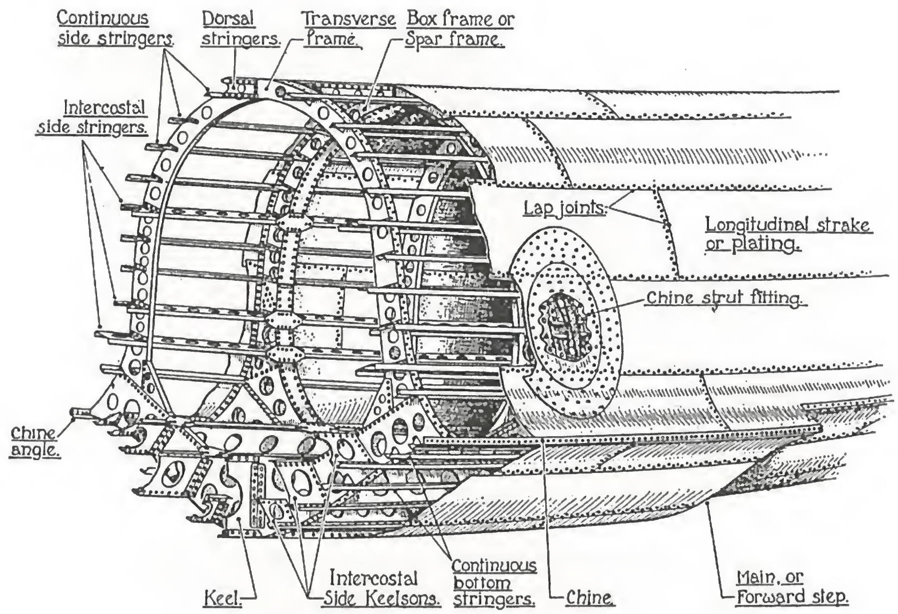


FIG. 55. LONGITUDINALLY PLATED HULL
("Manual of Rigging for Aircraft," by kind permission of the Controller of His Majesty's Stationery Office)

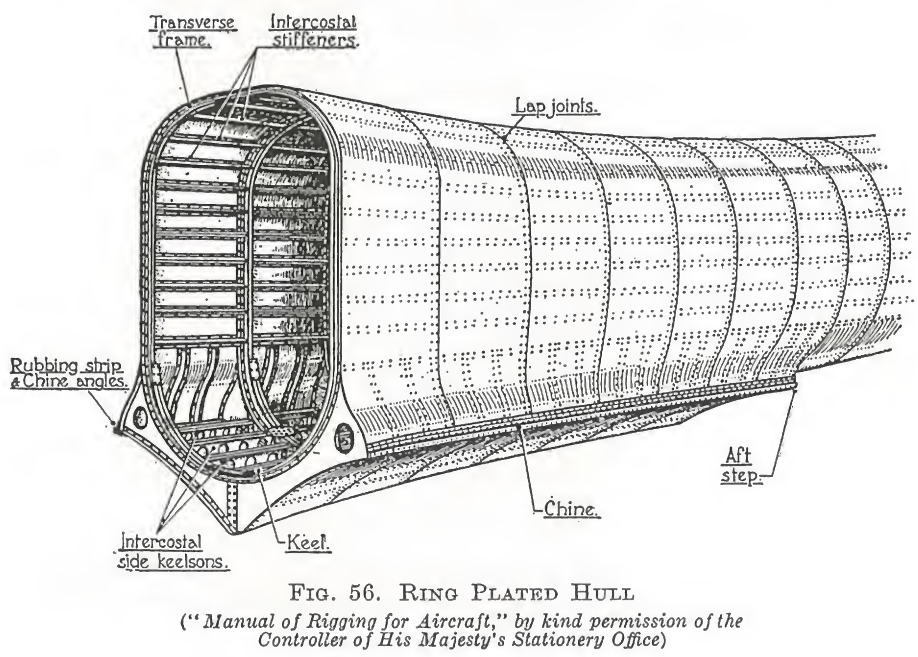


FIG. 56. RING PLATED HULL
("Manual of Rigging for Aircraft," by kind permission of the Controller of His Majesty's Stationery Office)

external struts and fixings which would tend to give false readings or measurements. This stage will also include the inspection of all external fittings, including those for the attachment of the other components and of the hull or float, to the superstructure. They should be examined for security and interchangeability. If no gauges are available for this latter check, resort should be made to trammels and direct measurement.

The method of testing for watertightness in the case of hulls is that of spraying water on all joints outside the hull through a hose-pipe fitted with a small nozzle, and giving a fine jet of water at high pressure. The detection of any leak will be made by examination on the inside of the component during the spraying operation.

Floats may be tested by placing a limited quantity of water inside the components, and after securing the watertight covers, the floats may be turned about so that all the joints in turn may be exposed to the water where, if any leaking takes place, it may be detected by examining the exterior of the float.

With these inspectional stages completed, final stamping will take place after examination for good finish, final protective coatings, and that the hull or float complies with the necessary drawings and specifications.

Repairs

When it becomes necessary to repair an extensively damaged hull or float, all the affected members and plating should be removed and replaced by new material in accordance with the original design.

Where structural members are only replaced in part, the conditions of an approved repair scheme should be applied, and if there is no already prepared scheme, the designing authority should be requested to furnish sketches or drawings for the repair.

Small holes in the shell-plating may be repaired by fitting a suitably sized patch of the same kind of material as the plating.

Explanation of Technical Terms used in Hull and Float Construction

Buttock Lines . . Longitudinal sections in a vertical plane.

Base Line . . Datum line from which all vertical dimensions are taken. The load water line is sometimes used as the datum and dimensions taken above and below.

Coamings . . . Vertical linings to cockpits, hatchways, and other openings in decks, etc.

Chine . . . Longitudinal member forming a connection between plating which does not continue in a fair curve in a vertical plane, forming a break or angle at the bilge.

Centre Line . . Line from which all transverse dimensions are taken.

Dorsal . . . The member which runs fore and aft on the top centre line of the hull connecting the top of the stem and stern post.

Diagonals . . Longitudinal sections in planes at various angles to the vertical plane arranged to cross-section lines as near to 90° as possible, used as fairing lines.

Fairing . . . A process by which the intersections of curved lines with other lines in the body plan, half breadth plan, and sheer plan are made to correspond. A fair curve is a curved line which has no abrupt or unfair inflexions in its length.

False Keel . . A member fitted under the main keel to deepen it or fitted over plating to protect it on taking the ground.

Half Breadth Plan . Half sections in an horizontal plane at water lines.

Inwales . . . Longitudinal members at junction of topsides and deck

Keel . . .	Longitudinal centre member running the length of the hull or float.
Keelson . . .	An inside keel fitted over the keel and floors.
Lay Off . . .	To transfer the design of the hull or float lines from the scale drawings to full size on the mould loft floor.
Stem . . .	A continuation of the keelson at the fore-end swept up at a more abrupt curve to meet the dorsal member.
Stern Post . .	The aft vertical member between keelson and dorsal member.
Sheer Lines or Profile	Side elevation.
Sections or Body Plan	Transverse sections on a vertical plan from which the moulds, frames, etc., are made.
Water Lines . .	Longitudinal sections in an horizontal plane.

CHAPTER V

INSPECTION OF COMPLETED AIRCRAFT

BEFORE commencing the inspection of a completed aircraft the ground engineer should be in possession of, or have sufficient knowledge of, complete information regarding rigging particulars, and all the various installations which are incorporated in the type of machine he is to inspect. In the majority of cases a handbook is issued by the designing firm containing an outline of leading particulars and of points requiring special attention. Reference should also be made to any applicable Ground Engineers' Notices. That the machine conforms to the "type" aircraft is also important.

Inspection of Rigging (see Fig. 57)

For this purpose the aircraft is placed in a flying position, supported at the jacking points with the wheels and tail skid off the ground. Indications are usually given of the positions of the jacking points or blocks, which are integral with the fuselage, but in the absence of these indications care must be exercised to ensure that when the machine is lifted off the ground no damage is done to the fuselage at or near the points of support. The flying position is obtained by levelling athwartships and fore and aft with the aid of a spirit-level on the recognized datum faces, which may be the top surfaces of an appropriate fuselage cross-strut and longeron respectively.

When the machine has been levelled suitable trestles should be placed under the lower wings at or near the outer interplane struts, in such a manner that they take no load of the machine, but are there in case the machine is accidentally dislodged.

The correct setting of the centre plane or planes should be checked by hanging plumblines on each side and measuring to symmetrical points on each side of the fuselage. The incidence is checked in a manner similar to that laid down hereunder for the wings and the cross-level by means of a spirit-level on the top of the centre section in line with the front spar.

The dihedral angles of the wings should next be measured by placing a straight-edge on the top of the wing surface, and as near as possible to, and usually parallel with, the front spar, and applying an Abney level or other suitable inclinometer.

The wing incidence is measured by placing the inclinometer on the straight-edge, which is pressed against the lower surface of the wing in line with one of the ribs. Special incidence boards are sometimes necessary for this check, depending on the wing design.

The incidence angles should be checked at the root end of each wing, and at the interplane strut fittings. The wing and thereby the centre plane stagger is checked by hanging plumblines over the leading edges of the top planes and taking the dimension from these lines to the leading edge of the lower wings in a fore-and-aft, and horizontal direction.

The fin, which is usually fitted on the centre line of the fuselage, may be proved for position by a plumbline and by measuring from the tailplane tips to the top of the fin on each side. The tailplane should be checked

for level athwartships and incidence in its two extreme and neutral positions.

The elevators should be examined that they are out of winding, and further that they are interconnected if the aircraft is in the aerobatic category. A plumbline should be hung near to the trailing edge of the rudder to check that the component is vertical. The extreme positions of the rudder, elevators, and ailerons should be checked that they are at least up to the drawing requirements, and that they are in the central positions

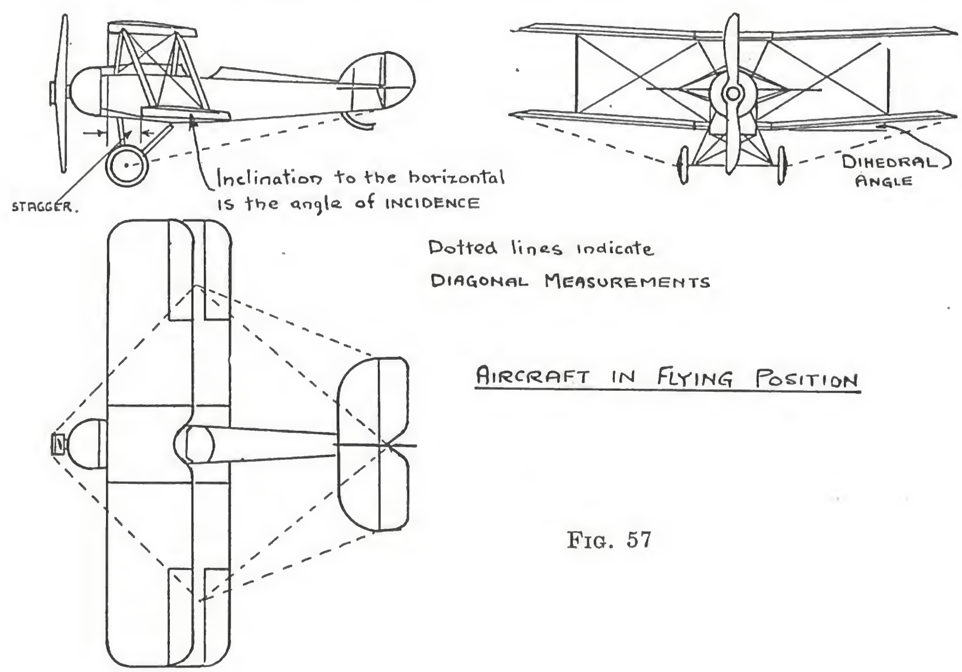


FIG. 57

when the cockpit controls are central. The ailerons should be correctly adjusted for droop (if any).

While dealing with the control surfaces, remember that when the control column is moved to the right, the right aileron moves upwards. When moved back the elevators move upwards. When the rudder bar is pushed forward with the right foot the rudder moves to the right hand of the operator, and when the tail adjusting wheel is rotated in the forward direction the incidence of the tailplane is increased. The slats should operate freely at all positions of their movements.

In order to ensure squareness and symmetrical fitting of the superstructure with regard to the fuselage, the following dimensions, which are known as "diagonals," should be taken—

1. Front or rear outer interplane strut to sternpost.
2. Front or rear outer interplane strut to tip of tailplane.
3. Front or rear outer interplane strut to airscrew hub.
4. Wingtip to end of undercarriage axle.
5. Sternpost to end of undercarriage axle.

These dimensions are taken on each side of the fuselage. Additional measurements between other suitable points may be taken if considered necessary.

In the absence of specified limits for angular and diagonal readings, the following general limits are given for guidance—

Front diagonals (3) .	$\pm \frac{3}{8}$ in. up to 20 ft. increasing by $\frac{1}{8}$ in. per 6 ft. increase.
Rear diagonals (1) including (2)	$\pm \frac{3}{4}$ in. up to 25 ft. increasing by $\frac{1}{4}$ in. per 8 ft. increase.
Wingtip to end of undercarriage axle (4)	$\pm \frac{1}{4}$ in. for 12 ft. and greater or less in proportion for other dimensions.
Sternpost to end of undercarriage axle	$\pm \frac{1}{4}$ in. for 15 ft. and greater or less in proportion for other dimensions.
Setting of tailplane fixed	Within $\pm 0^\circ$ 15′ of its angular position relative to the mainplane chord.
Moveable . . .	Must have its designed angular movement relative to the mainplane chord within limits of $+ 0^\circ$ 30′ $- 0^\circ$ at each end of range.
Control surfaces . .	Must have designed angular movements up and down from normal position each within $+ 1^\circ - 0^\circ$.

Should any of these limits be exceeded the reasons should be investigated by way of examination of the alignment of the components involved.

A definite stage of the final inspection should consist of the examination of all attachment points of components, including—

1. Wing attachments to the fuselage.
2. Wing attachments to the centre sections.
3. All strut attachments to the wings and fuselage.
4. Undercarriage attachment to the fuselage.
5. Tailplane and fin attachments to the fuselage.
6. Rudder and elevator and aileron hinge attachments.
7. Attachments to the wings.

All nuts must be securely locked by split pins or riveting, and all pins requiring split pins should have these inserted and properly opened. All bracing wires should be properly engaged in the threaded fork ends or anchorages. Fairing and cowling attachments must also be examined.

Landing Gear

The undercarriage should be checked for symmetrical disposition with respect to the fuselage by means of trammels or plumblines, which, coupled with the diagonals taken formerly, will ensure that it is satisfactory for wheel track. The wheels should revolve freely, and not be too slack, and must be adequately secured.

If it is a braked undercarriage, tests must be carried out to the design requirements. These tests may involve the application of torque to the undercarriage wheels, and this torque is applied by means of a wooden frame temporarily secured to the periphery of the tyre. The frame is arranged to carry a torque arm, and by applying different weights at the outer end of this arm the actual resistance of the brake may be found in such units as inch-pounds at any stage of application of the brake. (See "Brakes," page 81.)

The tail skid shock-absorbing device should be functioning satisfactorily, and a check of the security of attachment and alignment should be made. If a tail wheel is fitted, it is imperative that an earthing strip should be attached to the landing gear at some convenient point.

FLYING CONTROLS

So important is the satisfactory functioning of flying controls that the duplicate inspection referred to in the following paragraphs must not, under any circumstances, be omitted.

Before assembly into the control system, all details must be fully inspected and bear very clear evidence of that inspection. All cables must be spliced in accordance with the approved standard, and after splicing, but before final fitment to the aircraft, stretched under a tensile load of 50 per cent of the normal breaking load of the cable. Similarly, all roller chains which are a part of the control system, together with the end fittings, must be subjected to a tensile load of one-third of the ultimate load called for on the applicable drawings. Roller chains with spring links are prohibited; only those with a positive method of attaching the links are allowable.

All proprietary articles shall be subjected similarly and invariably to suitable proof loads. If a control wheel is used in the system, the following loads shall be applied—

(*a*) Push or pull on rim of wheel, the latter supported as in use. Load, 200 lb., applied 100 lb. on each side of the diameter between the spokes.

(*b*) A tangential force on the rim of the wheel; 75 lb. to be applied between the spokes.

The Inspection Leaflet No. 1 calls for the inspection of all aircraft controls as a duplicated inspectional operation. First, as an operation during assembly of the aircraft, and secondly, as a part of the inspection immediately preceding flight, and Inspection Leaflet No. 17 lays down that both of these stages of inspection must be carried out by different individuals. The following paragraph is extracted word-for-word from Inspection Leaflet No. 17, owing to its importance—

"It must be clearly realized that such duplicate inspection must be carried out invariably after all adjustments have been made. Not only is the functioning to be checked, but each separate control must be followed through from end to end, and a careful examination made of all joints, junctions, and locking devices. If dismantling, or any further adjustment of the controls is carried out thereafter, the above duplicate inspection must be repeated."

While the final inspection of the aircraft is being carried out, it must be at the sole disposal of the inspector, and no work of any kind carried out by the constructional staff.

Should the control system carry parts on which an adequate inspection cannot be carried out, that system should not be approved by the inspector. The following points should receive attention during both of the above-mentioned inspections—

1. That the direction of movements of controlling surfaces are correct in relation to the operating control levers or hand-wheels, and that the control operating levers in dual control aircraft are synchronous. When the control column is central all control surfaces should be neutral.

2. That all motions are free and regular throughout the system, without undue backlash.

3. That all cables lead fairly on to the pulleys or into fairleads.

4. That there is no possibility of the cables over-riding or leaving the pulleys.

5. That there is no possibility of jamming or fouling in any part of the mechanism.

6. That the stringing cord inside the planes is untouched by the controls.

7. That there are no parts likely to work loose and that there is ample locking of all details.

8. That there is sufficient length of thread, etc., in turnbuckles for subsequent adjustment of cables.

9. That no control surface fouls throughout the complete range of its movement.

10. That the tail adjusting gear index plate is graduated consistently with the movements of the adjusting gear.

11. That the pilot will have satisfactory freedom in all reasonable attitudes.

At the conclusion of the above flying control inspection, the necessary records must be made in the aircraft logbook, and signed for by each person making the check.

INSTALLATION OF ENGINE

In approaching this subject, it is first necessary to check that the engine installed is of the type approved for the purpose, and that the log-book indicates that the records are satisfactory. For instance, it would be essential to ensure that if the engine had been damaged while formerly installed in this or any other aircraft, that a certified overhauling was subsequently carried out. The alignment of the mounting has already been dealt with under "Fuselage Construction," but by check measurements taken before and after installation, preferably by trammelling, it can be ensured that no undue distortion has been caused on the mounting structure due to the weight of the engine.

The bedding of the engine on the mounting should be checked and also that the designer's requirements are met with regard to the packing between the engine and mounting. All securing bolts should be of the type called for on the drawing, and properly washered, tightened, and split-pinned or otherwise locked.

It is imperative that such clearances are allowed between the engine and its parts, and the structure of the aircraft, as will guarantee that no contact is made under any vibration while the engine is running.

Starting devices are not generally employed with light civil aircraft, but if used as they are on the larger-engined aircraft security of attachment, freedom of movement, should be carefully noted. The types of starters commonly in use are the hand or electric inertia starters, gas starters, and Hucks starters.

The method of attachment of the airscrew to the engine shaft should be carefully inspected. The assembly of the boss to the airscrew is an important operation. The bolts should be an easy fit in the holes, and the tightening of the nuts evenly carried out so as to take a uniform pressure all round on the boss flanges, that is, the flange should not be drawn more on one side than the other.

When mounting the airscrew, no weight should be taken on the shaft until the airscrew is completely home on the shaft; in other words, do not rely on the nut for pulling into position, or scoring or "picking up" may be the result. After tightening the nut, it should be locked in the approved manner.

After mounting, the airscrew should be checked for "track" in the following manner—

Place a pair of steps or similarly functioning device as near as possible to the tip of one of the blades, which should be approximately horizontal,

and make a measurement to a convenient point on the pitch face of the blade. Then rotate the airscrew, assuming it to be a two-blader, through 180°, and measure to a corresponding point on the other blade.

If the airscrew is comparatively new, the variation in the two measurements should be comparable with those laid down herein for the manufacture of airscrews. When an airscrew has been in service for some time, the variation of $\frac{1}{4}$ in. may be tolerated on an airscrew diameter of 8 ft., or *pro rata* for other diameters.

If the variation is in excess of this latter dimension, the cause of the error should be investigated by way of removal of the airscrew for the re-checking of all the factors involved, and if everything is found to be satisfactory with the airscrew, the positioning of the engine should next be queried.

It is difficult to lay down extreme limits which are hard and fast for airscrew track, for airscrews which are giving satisfactory service in flight may be beyond the above-mentioned limit of error. Incidentally, undue engine vibration due to excess track error may settle the question of the removal of an airscrew.

In the case of a twin-engined or multi-engined machine, a rough check for alignment may be made by placing the airscrews approximately horizontal, and dropping plumb-bobs over the tips of the blades, and at the same distance on each side of each blade, and checking them on to a line drawn through on the floor of the shop.

In order to check whether an airscrew is right-handed or left-handed, the following method may be employed: Place one of the blades in a vertical position above the boss, and standing in a position looking squarely on to the pitch face, the hand of the airscrew will be indicated by the side on which the leading edge occurs, that is to say, if, in this position, the leading edge is on the right hand, then the airscrew will be a right-handed one.

IGNITION SWITCHES AND WIRING

The general lay-out of the ignition system should first be proved to conform to the drawing requirements. The electric cables should not pass over the sharp edges of fittings or ducts, or be in contact with any moving parts which would damage the insulating material. They must be so installed as to avoid accidental damage from persons entering, leaving, or working on the aircraft.

The cables should run in ducts with flared ends wherever possible, and be accessible throughout their lengths. They should not be run in the same ducts as the wires of the lighting or wireless systems.

Terminal blocks should be provided at the junctions of detachable components to facilitate erection on dismantling of the aircraft. In the case of an aircraft with folding wings, the terminal blocks must be so placed as to avoid disconnecting the circuits when folding the wings.

Switches of an approved make are to be so installed that when in the "on" or running position, the levers of knobs are upward, as they work in the opposite way to the standard household switch. The cables should be bared just sufficiently to permit the core well entering the terminal hole. There is a liability of "shorting" if the cables are excessively bared, or if they protrude too far through the terminal hole.

In the case of twin-lever or twin-knob switches, it is advisable to arrange for the port lever to control the port magneto and the starboard lever the starboard magneto. In this manner, if there is a serious drop in engine revolutions when one magneto is cut out, the magneto with its set of plugs is at once determined.

The connection of the wires for the terminal blocks should also be examined in this respect.

The tests for electrical continuity and earthing are carried out with the aid of a lamp or bell and battery. Earthing is checked by disconnecting at the contact-breaker, and inserting a lamp or bell and battery in series with this wire, and any portion of the engine to form an earth. With the switch "off," the lamp should light, and be extinguished when the switch is put in the "on," or running position.

ENGINE CONTROLS

A careful end-to-end inspection should be made on all engine controls, which should be positively operated by straight push and pull rods, or torsion tubes. The security of the cranks and levers should be positive, that is, by brazing and pinning, or by the engagement of serrations, as levers operated by friction are not permitted. The cranking of control rods is prohibited unless definitely called for by design. All rods over 3 ft. in length should be provided with guides to prevent bowing, and ensure accurate movement.

Although controls should move with a minimum of friction, they should not be sufficiently loose to move during flight due to vibration. A check should be made for the correct direction of movement of levers both at the operating and engine end of each control. There should be no possibility of fouling throughout the complete ranges of movements.

All controls must operate in forward or upward directions for the opening or running positions and be suitably labelled to show their particular functions, and the "open" and "closed" positions.

There should be ample means of adjustment after all locking has been carried out.

INSPECTION OF HYDRAULIC CONTROL MECHANISMS

Coupled with the necessary checks that the whole of the installations and details thereof are in accordance with the drawing requirements and specifications, and that all previous inspections and releases have been effected, is the ground inspection for satisfactory functioning in all respects.

All pipe lines and internal parts of the system should be perfectly clean, for the smallest particle of foreign matter may cause poor functioning or even failure. Operating jacks should be correctly aligned and electrical circuits tested.

When ground-testing a hydraulic system which has its pressure supplied by an engine-driven pump, it is usual to disconnect the engine pump and connect it to a portable rig whereon it is suitably driven at approximately its normal engine revolutions. In testing the retractable undercarriage, the machine must be jacked clear of the ground. The entire system must be filled with the correct fluid and free from air. To accomplish this, "bleeding" points are provided, and during and after bleeding the fluid in the header tank should be maintained at its correct height. By bleeding at the several points provided, the fluid is allowed to flow in and from the system sufficiently to carry away with it any remaining air. Care should be taken to avoid contact of the fluid with the fabric covering of the aircraft component.

With the undercarriage set in the down position ready for functioning, the inspector should check all joints for freedom from leaks, that all catches are properly locked, that the indicators show the green light, and that the audible warning device is not operating.

During retraction it should be observed that all moving parts have adequate clearance and that there is no possibility of fouling: that the

audible warning device operates when the throttle is in the appropriate position, and that the amber light is showing. See Fig. 57A, which shows a Lockheed indicator.

The specified pressure should not be exceeded, and this should be checked by pressure gauges, which in turn will prove the appropriate functioning of the relief valve. With the undercarriage retracted, the locking catches

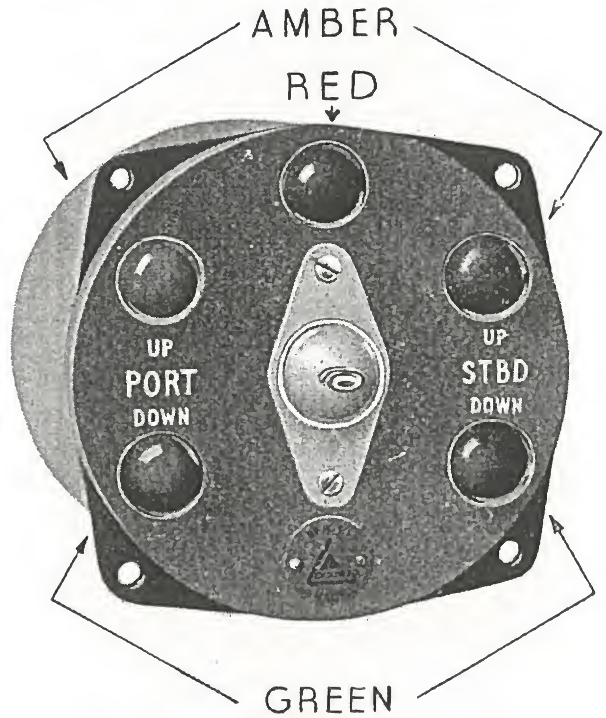


FIG. 57A

should be properly locked, and the red light and amber lights showing. After these tests a re-check should be made for leaks.

After the power-driven tests have been carried out, the undercarriage should be operated in each direction by the hand pump, and then lowered by using the mechanical emergency gear, making similar observations to those made during the power-driven operation.

The flaps should be tested while the undercarriage is in the down position. In functioning, it should be checked that the flaps do not wind, that they function simultaneously and equally, that the indicator records correctly, and that the specified pressure is not exceeded. The hand pump should be tried in like manner to that applied for the undercarriage.

INSPECTION OF FUEL, OIL, AND WATER SYSTEMS

The tanks of any of the above systems, together with connecting and securing parts and bolts, should bear evidence of proper inspection before installation.

During installation of these components, it is well to remember that for repair purposes, or alteration, they may have to be removed, and should be so installed as to facilitate easy removal. They should be so secured as to prevent any movement due to the aircraft landing, or to vibration.

No mounting should be made on any material which is moisture-absorbing, such as felt, without some insulating material being used to protect the tank from corrosion. A clearance of at least $\frac{1}{4}$ in. should be allowed between a tank and any other member or part of the aircraft (apart, of course, from its attachment) to avoid the possibility of chafing or wearing.

All copper piping under 1 in. in diameter should be in the fully softened condition, in which condition it may be bent and worked without further heating. Where heating is requisite, as in the case of large copper pipes, a careful control should be kept of the temperature during the subsequent imperative annealing.

All pipes should be fairly led to their end connections so that they are not pulled or strained into alignment on fixing. They should also be

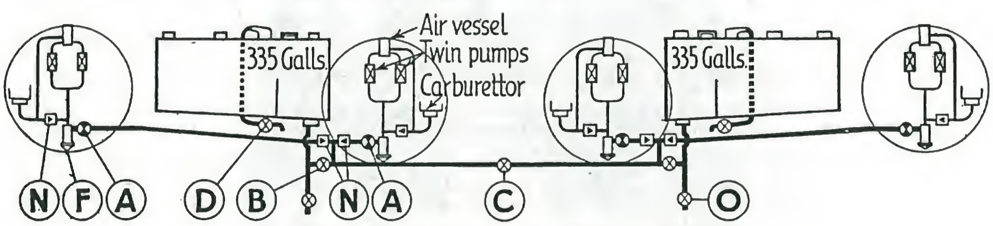


FIG. 57B. THE AW27 PETROL SYSTEM

A* Engine supply cock
B† Wing-tank cock
C† Tank balance cock
D† Refuelling cock
F Filter
N Non-return valve
O† Off-loading cock

* Operated by Captain. † Operated by First Officer.

supported at regular intervals by efficient clips. Many pipes have fractured in service due to the neglect of this point, and sometimes with very serious results.

A systematic check should be made of the locking of all joints, filter covers, etc.

All of the three systems should be checked to determine that there is no possibility of air locks, and that the liquid will form one continuous flow through the particular system. Air locks are most likely to occur in pipes having a profile shape of an inverted "U," the air becoming locked in the top of the curve and arresting the liquid flow at that position.

All joints, accessories, and piping should be free from leaks when the system is full. The petrol flow is checked by disconnecting the union nut at the carburettor, and taking a measured flow on a level with the joint, with the aircraft in a climbing attitude, which, for practical purposes, is usually with the tail skid on the shop floor, and the tank under test 10 per cent petrol filled.

Further, if under flying conditions three engines on one aircraft are to be served with fuel from any one tank, then the petrol flow should be taken at the three engines simultaneously. As the result of this test, the fuel supply should be at least 100 per cent in excess of the maximum requirements of the engine or engines, or such less amount than 100 per cent as is officially authorized.

In Fig. 57B is seen a diagrammatic view of the petrol system employed on the "Ensign" type of aircraft (Armstrong Whitworth), with the names of the various parts of the system. It should be noted that each of the two petrol tanks, one port and the other starboard, normally supplies two engines through the engine-driven pumps; but if necessary, one tank will supply all the engines if the balance cock is opened. The tanks are situated in the nose of the wing, one on each side of the fuselage. They

are connected by the long horizontal balance pipe shown in the diagram, with a cock provided in the middle for balancing or isolating the petrol in the tanks as desired.

The fuel does not flow direct to the carburettor, but in each case passes through a non-return valve to prevent surging, then through an engine supply cock (one for each engine) to the filter, thence through the engine-driven pump to the carburettor.

If an engine pump should fail for any reason and impede the petrol flow, it is possible for the fuel to flow by gravity by short-circuiting the pumps. This process is automatic in operation, as there is a non-return valve between the lower ends of the inlet and delivery pipes of the pumps.

If cocks or non-return valves are removed for the purpose of renewal or maintenance, extreme care should be taken to avoid incorrect reassembly, the results of which are very obvious. External indication of direction of flow, "on," and "off" is invariably provided on the accessory.

To carry out a petrol-flow test with such a system as this, it is usual to employ a pump rig. This rig consists of a petrol pump driven so as to supply the same quantity of fuel as that supplied by the engine pump when the engine is doing maximum revolutions per minute. The pump should be placed on the same level as the engine pump, and the supplementary piping of equivalent bores and runs to the engine piping connected into the petrol system to enable the flow to be taken at the carburettors as it would with the engine pump functioning. This should prove that the petrol supplied is at least equal to that required by the design authority.

Pumps which are fitted as parts of the aircraft, that is, as apart from those which may be incorporated in the engine, should be spun at their normal flying revolutions, and checked for functioning and supply. The method of spinning is usually that of connecting the pump spindle to the driving shaft of a suitable motor.

Oil coolers should be checked especially for assembly, and that the oil has a clear passage through the cooler.

The water system should be inspected throughout for leaks and all parts for security of attachment.

If a retractable radiator is fitted it should be examined throughout the whole range of movement.

ELECTRICAL SERVICES

All candidates should acquaint themselves with the simple formula $C = \frac{E}{R}$ where C = amperes, or units of current; E = volts, or units of electromotive force, and R = ohms, or units of resistance. (One megohm = 1,000,000 ohms.) With this formula well understood, it is easier to go ahead on electrical testing.

In testing electrical circuits for insulation resistance, a 500 volt megger should be used. The minimum resistance registered when testing between any two poles should be 2 megohms. It is usual, however, when testing for insulation resistance "between poles," to bunch all leads connected to the red terminal of the voltage control box, and apply the formula $\frac{\text{20 megohms}}{\text{No. of points in circuit}}$, the value of which should not exceed 2 megohms. Circuits under test should be closed at the switches but have lamp bulbs and similar detachable items removed.

If the figure obtained is unsatisfactory, more local tests should be

carried out to discover the exact position of the breakdown, in order that the wire or part may be replaced.

In testing for continuity of wiring, a battery should be used with a lamp or bell as an indicator.

An aircraft which has to be fitted for wireless should have all of the metallic parts metallically bonded, and the aircraft should be checked for this from one component to another, say from wingtip to wingtip and from rudder to interplane strut, etc. The Inspection Leaflet dealing with this subject should be carefully studied, and all the points mentioned therein should receive due attention.

INSTALLATION OF INSTRUMENTS AND EQUIPMENT

In the majority of cases nearly all aircraft instruments are secured to a main instrument board, and should be so placed that the pilot can read them without undue effort when seated in a normal flying position. The instrument board should be adequately secured and free from any undue vibration in flight, or when the engine is ground running.

All instruments installed must be of approved types. The question of the approval of the type of an instrument may be overlooked due to an inspector's keenness to attend to the question of an instrument having passed approved inspection. Both points are important, however.

As approximate checks can only be made on instruments after installation, unless portable calibrators are available, the question of approval and certification of satisfactory calibration before attachment in the aircraft is all the more important. Instruments are usually released and fully certified for functioning by a firm whose inspection organization has been duly authorized, but failing this, no instrument should be used before being tested and certified at an approved test house. If at any time there is doubt regarding the satisfactory functioning of an installed instrument, it should be removed and properly calibrated.

The following observations or checks should be made when inspecting the equipment in the aircraft, in addition to checking that the instruments are properly secured and all joints are tight.

Airspeed Indicator. Apply a slight air pressure, say by blowing down the pressure tubing at the pressure head end, and hold this pressure for about half a minute. During this time the indicator needle should remain stationary. If, when blowing down the tube the needle moves in the wrong direction, the Pitôt tubes are wrongly connected. A standard water gauge or portable calibrator may be used to check an airspeed indicator if the accuracy is suspected.

Altimeter. The milled knob at the bottom of this instrument should be turned to see that the dial is rotated satisfactorily by the pinion on the racked periphery. If the instrument is suspected of functioning wrongly in flight, it should be removed and calibrated.

Pressure Gauges. When not functioning, the indicators should stand at zero. Further checks may be made when the engine is running by applying pressure in the fuel tanks, etc., or by the use of a portable calibrator.

Thermometers. These may be roughly checked for comparison against the temperature in the shop or hangar where the range of the instrument includes the temperature of the atmosphere. In the case of radiator or oil temperature thermometers, the connection and securing of the capillary tubes should be carefully examined.

Engine Revolution Counter. This should stand at its lowest reading when the engine is not running. The flexible drive should be installed with

as few bends as possible, and no bend should have a radius of more than 9 in. The connecting ends of the drive to the gearbox and the instrument should be examined.

Cross Level. The bubble should be central when the aircraft is level athwartships.

Turn Indicators. The makers' instructions should be carefully followed regarding the fitting of any particular indicator, but the aircraft should always be in flying position during fitment in order to check that the instrument is correctly levelled and squared.

Compass. An installed compass should be examined for—

1. Pivot friction. This is done by deflecting the magnet system through approximately 5° with the aid of a corrector magnet. When this magnet is removed, the magnet system of the compass should return easily to its original position.

2. Discoloration of the liquid, and that the card is easily readable. The liquid should be free from bubbles.

3. That the anti-vibrational devices supporting the bowl are in good condition. The bowl should not foul any part of the aircraft.

4. That the compass is supported on a level platform, and that no ferrous metals are used for supports or security. No ferrous metal fittings should be so close as to cause errors in the readings.

5. The corrector box should be placed under the centre of the compass with the magnet holes positioned fore and aft and athwartships.

Safety Belts and Harness. The regulations regarding this equipment should be carefully observed. Every belt should be proof loaded before fixing in the aircraft. Two-piece belts should be so attached in the aircraft as to prevent slipping downwards from the chest to the abdomen.

All attachments and fittings connecting the belts to the aircraft should be capable of withstanding a load consistent with the strength of the belt.

The use of leather as a material for safety belts is prohibited.

CENTRE OF GRAVITY OF AN AIRCRAFT

The Air Navigation Directions lay down that every flying machine shall be weighed to the satisfaction of the Secretary of State before a Certificate of Airworthiness (C. of A.) is issued in respect thereof, and at such times after the issue of a C. of A. as the Secretary of State may require. Every flying machine for which a C. of A. is in force shall bear clearly painted upon it in a prominent position, its weight empty, or tare weight, including the water in the radiators, as ascertained at its last weighing, and the maximum total weight authorized for it as shown in its C. of A. In addition, the machine must carry displayed in a prominent position inside it a weight schedule showing what items of equipment, if any, were included in the weight empty, or tare weight.

With reference to the loading of an aircraft, it is important from a safety point of view that for any particular load up to and including the maximum permissible, the centre of gravity shall be within the range stated in the Certificate of Airworthiness for the aircraft.

The position of the centre of gravity of an aircraft will be determined in terms of its relative position to the chord of the aircraft bottom plane, or to the datum point and the datum level if the C.G. range is stated in these terms—

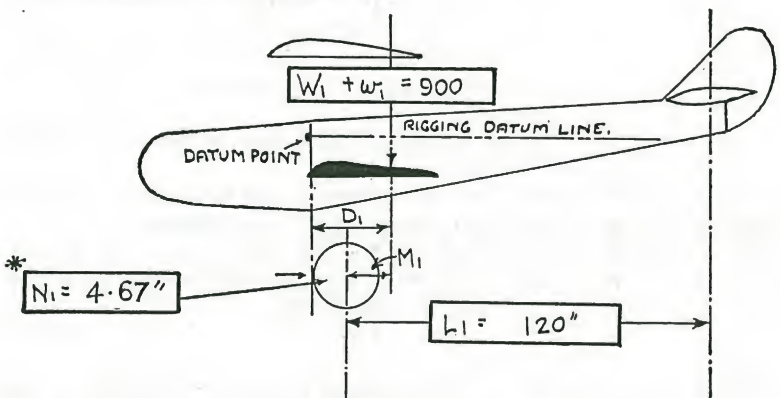
1. The longitudinal position of a plane perpendicular to the chord and containing the C.G. will be determined in terms of inches measured along

the chord line either in front or behind the leading edge, or, similarly, behind or in front of the point fixed as the datum point on the aircraft.

2. The vertical position of the C.G. will be determined in terms of its perpendicular height in inches above or below the chord line or datum line.

3. The transverse position of the C.G. is always assumed to be in the plane of symmetry of the aircraft.

‡ ~~WITH RIGGING DATUM LINE HORIZONTAL.~~
WITH CHORD HORIZONTAL.



READING ON SCALES	910
LESS WEIGHT OF TACKLE	20
= WEIGHT ON FRONT SUPPORT (W1)	890 LBS

READING ON SCALES	16. LBS.
LESS WEIGHT OF TACKLE	6 LBS.
= WEIGHT ON REAR SUPPORT (w1)	10 LBS.

FIG. 58

The method of determining the longitudinal position of the C.G. is given in the following paragraphs.

The C.G. is first calculated from figures obtained by weighing the aircraft in the tare condition, that is, the completed aircraft less pilot, passengers, petrol, oil, and all removable equipment, but with the water in the radiators (if any). In this condition the aircraft is placed with its landing wheels and tail skid or wheel on scales so that it is in such a position that its datum line is in an horizontal position, or set so that the longitudinal plane containing the chord line of the bottom main planes is horizontal.

The C.G. is then calculated as laid down in the diagram shown in Fig. 58. When the front support is horizontally in front of the leading edge or

$$M_1 = \frac{w_1 \times L_1}{W_1 + w_1} = \frac{(10) \times (120)}{(890 + 10)} = 1{\cdot}33 \text{ in.}$$

The distance that the plane containing the tare C.G. is behind the *leading edge / datum point is—

$$D_1 = M_1 + N_1 = (1{\cdot}33 \text{ in.}) + (4{\cdot}67 \text{ in.}) = 6 \text{ in.}$$

datum point, this measurement corresponding to N_1 in the diagram should be expressed as a negative value. All measurements must be taken on both the port and starboard sides of the aircraft, and from these the

* Delete where inapplicable.

mean values are calculated. If a negative load occurs at w in the zero angle of incidence, or when the datum line is level, an extra moment may be added for convenience in order to stabilize the aircraft in that position, and subsequently deducted in the calculations.

Having determined the tare C.G., the C.G. for any specified loading may be calculated as shown in Table III. It must be clearly understood that when the aircraft is levelled to the rigging datum line, the measurements are made from the datum point, and the position of the C.G. registered therefrom, but if the chord line of the mainplane is used, then the measurements are correspondingly made from the leading edge, and the C.G. referred to this point.

In the diagram and table, simple illustration figures have been inserted to facilitate explanation. It will be seen that the position of the horizontal C.G. for the particular loading is obtained by dividing the resultant moment by the total load and in this case is 6·9 in. behind the leading edge.

For purposes of calculation, the following weights should be used—

Weight of fuel . .	7·7 lb. per gallon
Weight of oil . .	9·7 lb. per gallon
Weight of crew . .	170 lb. per person

When estimating approximately the number of passengers who may be carried for the commercial load available, the average weight of a person may be taken as 170 lb.

* When the front support is horizontally in front of the †datum point / leading edge this measurement is to be expressed as a negative value.

† Delete where inapplicable.

TABLE III

Correction of Tare C.G. for the Undermentioned Loading

Longitudinal along * {Rigging Datum Line / Chord Line} Position of Load and its Moment				Load	Weight in Lb.
In Front of * {Datum Point / Leading Edge}		Behind * {Datum Point / Leading Edge}			
Distance in Inches	Moment (in lb.)	Distance in Inches	Moment (in lb.)		
		6	5,400	Aircraft (Tare)	900
		40	6,800	Pilot	170
		1	170	Passenger	170
6	1,800			Petrol	300
3	180			Oil	60
		20	1,000	Luggage or any other Loading	50
	1,980		13,370	Total Weight	1,650
			11,390	Resultant Moment (larger minus the smaller)	
		6·9		C.G. Position $\frac{\text{Resultant Moment}}{\text{Total Weight}}$	

* Delete where inapplicable.

APPENDIX

GLOSSARY OF AERONAUTICAL TERMS

EXTRACTED FROM

THE BRITISH STANDARD GLOSSARY OF AERONAUTICAL TERMS

By kind permission of the British Standards Institution, 28 Victoria Street, London, S.W.1, from whom copies of this Glossary and all B.S. Specifications can be obtained.

Acorn. A device introduced at the intersection of bracing wires to prevent abrasion.

Adjusting Gear for Aileron, Rudder, Fin, or Tailplane. Mechanism provided for altering the trim of the control surface during flight.

Aerobatics. Evolutions voluntarily performed with an aircraft other than those required for normal flight.

Aerodyne. A generic term for aircraft which derive their lift in flight chiefly from aerodynamic forces.

Aerofoil. A surface designed to produce an aerodynamic reaction normal to the direction of motion.

SLAT. An auxiliary aerofoil forming the forward portion of a slotted aerofoil with forwardly located slot.

Aerofoil Section. The outline of the section of an aerofoil in a plane parallel to its plane of symmetry.

Aeroplane. A flying machine with fixed wings.

AMPHIBIAN. An aeroplane provided with means for normally rising from, and alighting on, either land or water.

LANDPLANE. An aeroplane provided with means for normally rising from and alighting on land.

SEAPLANE. An aeroplane provided with means for normally rising from and alighting on water.

Float Seaplane. A seaplane provided with floats as its means of support on water.

Flying Boat. A seaplane of which the main body or hull is also the means of support on water.

Ailerons. Movable flaps situated at or near each wingtip and designed to impart a rolling motion to the aerodyne by their rotation in opposite senses.

Aircraft. All types of air-supported vehicles.

Airscrew Hub. A detachable metal part by which a complete airscrew is mounted on the airscrew shaft.

Airscrew. I—Generically, all types of screw with helical blades designed to rotate in air.

II—Specifically, a power-driven screw designed to produce thrust by its rotation in air.

PUSHER AIRSCREW. An airscrew designed to produce compression in the airscrew shaft.

TRACTOR AIRSCREW. An airscrew designed to produce tension in the airscrew shaft.

LEFT-HAND AIRSCREW. An airscrew revolving counter-clockwise to an observer behind the aircraft.

RIGHT-HAND AIRSCREW. An airscrew revolving clockwise to an observer behind the aircraft.

Note. In a tractor system the "hand" of the airscrew is the same as that of the engine, but in a pusher system it is the opposite.

SWIVELLING AIRSCREW. An airscrew capable of being turned so as to transmit thrust in any direction within a fixed plane.

VARIABLE-PITCH AIRSCREW. An airscrew whose blades are so mounted that they may be turned about their axes to a desired pitch while the airscrew is in rotation.

Note. This term is not to be used for an airscrew whose blades are adjustable only when stationary.

Air Speed. Speed relative to the air, as distinct from speed relative to the ground.

Airworthy. Complying with the prescribed regulations for a Certificate of Airworthiness.

Angles. Aileron angle—Elevator angle—Rudder angle. The angle between the chord of the movable portion of an aerofoil and the chord of the corresponding fixed surface.

ANGLE OF INCIDENCE (RIGGING). The angle between the chord line of the mainplane and the horizontal when the aeroplane is in the rigging position.

Note. Not to be confused with the true Angle of Incidence, which is the angle between the chord line of an aerofoil and the relative wind.

ANGLE OF SWEEP-BACK. The angular set back of the mainplanes relatively to the fuselage or hull.

DIHEDRAL ANGLE. The angle at which both port and starboard planes of an aeroplane or glider are inclined upwards or downwards to the transverse axis. The dihedral angle is the acute angle between the span axis of either plane, and the transverse axis. If the inclination is upward the dihedral is positive.

TAIL-SETTING ANGLE. The acute angle between the chord line of the mainplane and the chord line of the tailplane. If the latter is at a greater inclination to the horizontal than the former the angle is said to be positive.

Aspect Ratio. The ratio of the span to the mean chord of an aerofoil, i.e. the ratio of the square of the maximum span to the total area of an aerofoil.

Balanced Surface. A control surface which extends on both sides of the axis of the hinge or pivot in such a manner as to reduce the moment of the air forces about the hinge. The portion of the surface in front of the hinge is referred to as the "balance" or "balance portion."

Banking. Angular displacement about the longitudinal axis for the purpose of turning.

Boss. The central portion of the airscrew by which it is attached to the airscrew hub or shaft.

Cabane. A pyramidal arrangement of struts on an aerodyne. (Sometimes called Pylon.)

Camber. Curvature of a surface of an aerofoil.

Ceiling.

ABSOLUTE CEILING. The height at which the rate of climb would be zero in Standard Atmosphere under specified conditions.

SERVICE CEILING. The height at which the rate of climb has fallen to a certain defined limit (e.g. 100 ft. per minute).

Centre Section. The central portion of the mainplane. (Top or bottom.)

Chord or Chord Length. The length of that part of the chord line which is intercepted by the aerofoil section.

Chord Line. The chord line is the straight line through the centres of curvature at the leading and trailing edges of an aerofoil section.

Note. In the past the term Chord Line has been used as indicating the common tangent to the bottom surface of an aerofoil. The new definition has been adopted for precision.

Control Column. The lever or pillar supporting a hand-wheel by which the elevator and aileron controls are operated.

Elevator. A movable horizontal surface for controlling the motion of an aerodyne in pitch.

Fin. A fixed vertical surface affecting the lateral stability of the motion of an aerodyne. When fitted at the rear end of the body it is termed the tail fin.

Flap. A hinged rear portion of an aerofoil.

Fuselage. The main structural body of an aerodyne, to which the mainplanes, tail unit, etc., are attached.

Gap. The distance between a plane and the one immediately above or below it.

Leading Edge. I—The forward edge of a streamline body or aerofoil.

II—The structural member there situated.

Levers. Aileron lever—Elevator lever—Rudder lever. The lever arm by which the control surface is connected to the actuating mechanism.

Nose heaviness. A tendency of an aircraft to pitch down by the nose in flight.

Overhang. I—The extent to which the wingtip of one of two superimposed planes projects beyond the tip of the other.

II—The distance from the outer point of support to the tip of an aerofoil.

Pay (or Commercial) Load. That part of the useful load from which revenue is derived—i.e. passengers, mails, and freight.

Pitch. Experimental Mean Pitch. The distance through which an airscrew advances along its axis, during one revolution, when giving no thrust.

Geometric Pitch. The distance which an element of an airscrew blade would advance in one revolution when moving along a helix to which the chord of that element is tangential.

Note. The geometric pitch of an element distant two-thirds of the tip radius from the axis of rotation is usually referred to as the "pitch" of that particular airscrew and is marked on it.

Pressure Head. A combination of pitot and static pressure tubes for use in conjunction with a differential pressure gauge for determining the speed of a current of air.

Rigging. The relative adjustment or alignment of the different components of an aerodyne.

Rigging Position. The position in which, with the lateral axis horizontal, an arbitrary longitudinal datum line is also horizontal.

Rudder. A movable vertical surface for controlling the motion of an aerodyne in yaw.

Rudder Post. The main vertical member of a rudder to which the rudder hinges are attached.

Rudder Bar. The foot-bar by means of which the rudder is operated.

Servo Control. A control devised to reinforce the pilot's effort by an aerodynamic or mechanical relay.

Sheathing. Thin sheet-metal or other material attached to the tips and leading edges of wooden blades to prevent abrasion by water, sand, etc.

Slipstream. The stream of air discharged aft by a revolving airscrew.

Span. The overall distance from wingtip to wingtip.

Spinner. A streamline fairing fitted co-axially, and rotating with the airscrew.

Stability. The quality by virtue of which any disturbance of steady motion tends to decrease. A given type of steady motion is stable if the aircraft will return to that state of motion after disturbance without movement of the controls by the pilot.

LATERAL STABILITY. The stability of the motions out of the plane of symmetry, i.e. of side-slipping, rolling, and yawing.

LONGITUDINAL STABILITY. The stability of the motions in the plane of symmetry, i.e. of the rise and fall, forward motion and pitching.

Stagger. When one of two superposed planes is disposed ahead of the other, the planes are said to be staggered. When the top plane is ahead of the bottom the stagger is said to be positive.

Stall. To be at or above the angle of incidence corresponding with the maximum lift coefficient of an aeroplane.

Static Unbalance. An airscrew is in static unbalance if, when concentrically mounted on a spindle supported by knife edges, it will not remain at rest in all positions.

Stern Post. The rearmost upright member of the fuselage or hull of an aerodyne.

Note. Not to be confused with Rudder Post.

Strut. A structural member intended to resist compression in the direction of its length.

DRAG STRUTS. Struts incorporated in the framework of an aerofoil to carry the loads induced by the air forces in the plane of the aerofoil.

INTERPLANE STRUTS. Vertical or inclined struts connecting the spars of a plane to those of the plane above.

JURY STRUT. A strut inserted to provide temporary support for a structure. A common example is the strut used to support the wing structure of an aerodyne during folding.

Tail Heaviness. A tendency of an aircraft to pitch down by the tail in flight.

TAIL-SKID. A member taking the weight of the rear end of the fuselage on the ground.

TAIL-SKID BAR. The crosspiece on a steerable tail-skid.

TAIL-SKID SHOE. A replaceable covering on the end of a tail-skid to take the wear.

Tail Wheel. A small wheel sometimes fitted in place of a tail-skid.

Taxying. Movement of an aircraft under its own power, in contact with the earth.

Townend Ring. A ring of aerofoil section arranged round a radial engine to reduce its drag by deflecting inwards the air flowing past it.

Trailing Edge. I—The rear edge of a streamline body or aerofoil.

II—The structural member there situated.

Undercarriage. That part of the alighting gear which embodies the main wheels, skids, or floats.

Useful Load. The gross weight less the tare weight.

Wash-in. Increase of angle of incidence towards the wingtip.

Wash-out. Decrease in angle of incidence towards the wingtip.

Weights. FLYING WEIGHT. The total weight of an aircraft at the beginning of a flight.

Gross Weight. The maximum flying weight of an aircraft permissible under the Regulations obtaining.

Note. For civil aircraft this is the maximum authorized weight shown on the Certificate of Airworthiness.

Tare Weight. The weight of an aerodyne complete in flying order with water in the radiators, but no crew, fuel, oil, removable equipment or pay load.

Wires. Drag-wires. Wires or cables the principal function of which is to transfer the drag of the planes to the body or other part of the structure.

Anti-drag Wires. Wires to resist forces in the opposite direction to the drag.

Incidence Wires. Wires or cables bracing the mainplane structure in the plane of a pair of front and rear struts.

Lift Wires. Wires or cables the principal function of which is to transfer the lift of the wings to the body or other part of an aerodyne. (Sometimes called Flying wires.)

Yawing. Angular motion about the normal axis.

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D—(A.3)

AERO-ENGINES

INSPECTION OF BEFORE FLIGHT

("C" LICENCE)

The Air Ministry, whilst accepting no responsibility for the contents of this book, recognizes it as a textbook that should prove to be of value to intending applicants for Ground Engineers' licences

CONTENTS

PART I ("C" LICENCE)

INSPECTION OF AERO-ENGINES BEFORE FLIGHT

By R. F. Barlow

PART II

THE LAW RELATING TO CIVIL AVIATION

By A. McIsaac

CONTENTS

PART I

INSPECTION OF AERO-ENGINES BEFORE FLIGHT

By R. F. BARLOW

GROUND ENGINEERS' CATEGORY "C" LICENCE

THE AIR NAVIGATION DIRECTIONS

THE duties of a ground engineer licensed in Category "C" comprise carrying out top overhauls and repairs, installing and maintaining those types of engines covered by his licence, and the certification of such work in the approved manner.

The requirements of the British Government regarding the manufacture, maintenance, and operation of Civil Aircraft holding a British Certificate of Airworthiness are contained in the Air Navigation Directions (A.N.D.) which are issued by the Secretary of State for Air, under Article 30 of the Air Navigation (Consolidated) Order, 1923, and can be purchased from His Majesty's Stationery Office.

It is a condition of the issue of a licence that the candidate shall be thoroughly conversant with these directions, particularly with those sections dealing with the issue of licences, the maintenance of aircraft, the maintenance of records, and the certification of all work carried out by or under the supervision of a ground engineer. New candidates must therefore be prepared to be cross-examined on their knowledge of these Directions, as a preliminary to the technical examination, and a lack of knowledge of this subject may adversely influence the recommendations of the board of examiners.

Before presenting themselves for the first time, candidates are therefore strongly recommended to make a close study of these Directions, paying particular attention to the following sections—

Section II. This section deals exclusively with the manufacture of aircraft. (NOTE. The term "Aircraft" referred to throughout the Directions is to be regarded as a general one only, and is intended to cover not only the air-frame, but also aero-engines, instruments, and all other accessories.) It may on that account appear to be of no interest to the ground engineer concerned in repair and maintenance only. Some knowledge of this section is, however, of value, since a better appreciation of the method of control of the manufacture of aircraft in this country may be gained therefrom, which in turn will result in the candidate understanding the reason for, and value of, the documents which accompany that control and without which a ground engineer is not permitted to accept or to fit spare parts.

For the benefit of those not fully conversant with the system in operation, it may be explained that while the Director of Aircraft Inspection, as representing the Secretary of State for Air, is *the* authority on all matters pertaining to the inspection of Civil Aircraft, the Air Navigation Directions

impose on all manufacturers of aircraft and accessory parts thereof the need for maintaining an efficient inspection staff who are responsible for ensuring, by suitable testing, that all materials used in the construction of such aircraft and accessory parts are in accordance with specification requirements, and that all parts are strictly in accordance with the drawings and/or specifications that have been approved by the Air Ministry.

Firms whose inspection organization meet these conditions are "approved" by the Air Ministry, and their work is supervised by the Director of Aircraft Inspection (A.I.D.). Such "approvals" are not confined to constructors of complete aircraft, aero-engines, etc.; but are also issued to firms producing raw material, stampings, forgings, and in fact to all subsidiary processes connected with the manufacture of aircraft.

Firms so "approved" are authorized to "release" and to issue "release notes," covering raw material, the finished product, etc., according to the terms of their approval.

In order to safeguard against the release of materials, etc., by unauthorized persons, it is required that all release notes shall bear a certificate in the following form—

> "I hereby certify that the whole of this material and/or parts, covered by this advice note, have been inspected and tested and conform with specification —— and drawings relative thereto in accordance with the conditions of the A.N.D."

The Certificate must be signed by a responsible member of the firm by whom the advice note is issued. In addition the document must quote the Air Ministry Authority under which it is issued. This authority takes one of two forms—

(i) A series of six figures followed by two, e.g. 123456/30, or
(ii) A.I.D./1068/33/Leeds Office.

It should be noted that release or advice notes are not issued in the case of complete aircraft or complete engines. In the former case the "Certificate of Airworthiness" meets all the requirements in this respect, while in the latter case, "release" is covered by the certificate contained in the engine log book.

Section III. Explains the terms and conditions under which licences are issued, and new candidates should study these conditions before sending in their applications in order to satisfy themselves that they have the required qualifications and have reasonable prospects of passing the examination (which is an oral one). This will prevent disappointment and loss of time and money in respect of fees and travelling expenses, which are not recoverable under any conditions.

Section IV. Is a particularly important one for the ground engineer as it contains details of, and instructions in the preparation of daily certificates of safety for flight, without which no aircraft plying for hire and award may fly.

The preparation of, or at least the signature of these certificates constitutes an important part of the duties of a ground engineer, and new candidates are advised to study the terms in which the certificates are drawn up, since they emphasize the responsibilities of the signatories.

The certificates are only valid for a period of twenty-four hours, hence the reference to them as "daily" certificates.

Section V. Deals with the repair, overhaul, and the embodiment of modifications. It also gives the form of certificate that must be prepared following such work being carried out.

Regarding modifications, all approved alterations or modifications to aircraft, aero-engines, etc., that in any way affect the safety of the aircraft

are notified by the Air Ministry by means of "Notices to Aircraft Owners and Ground Engineers," which are issued gratis to all registered owners of aircraft and persons holding a ground engineer's licence.

It will be noted that these notices invariably quote a date by which the modification with which they deal must be embodied, failing which a renewal of the certificate of airworthiness of any aircraft concerned will be refused.

It is of importance, therefore, for ground engineers to pay close attention to these notices, since failure to embody all relevant modifications in the aircraft for which they are responsible will be recorded against them. A second lapse of a similar nature would probably result in their licence being withdrawn.

A complete set of these notices in force at the time a licence is first issued is forwarded with the licence, and it is a sound plan to analyse these carefully and tabulate those concerned under the engines included in the licence held. These tables will form a reliable and readily accessible record from which to check a particular engine under examination for the first time.

No matter how familiar one may be with an engine, there is always the possibility of having the attention diverted during the process of final checking, which very often results in some points being overlooked.

In addition, certain desirable modifications, which have been approved by the Air Ministry, are introduced from time to time. These are notified to the owners by the authority responsible for recommending the renewal of the Certificate of Airworthiness. While the issue of that certificate is not affected by the inclusion or omission of this class of modification, they should, wherever practical, be embodied at the earliest opportunity.

Section VIII. Is of importance since it amplifies the details, given in Section II (*d*), of the list of instruments that are required to be fitted under varying conditions of operation of an aircraft.

When checking off the installation of the engine(s) of a machine not previously certified by him, the ground engineer must satisfy himself that the instruments fitted are in accordance with the requirements of this section and that they function correctly.

Section X. Deals with the preparation and maintenance of Log Books. The "C" Licensee is only responsible for the maintenance of the engine log book (C.A. form 28) and in it must be entered particulars of all running by the engine for which it has been issued, together with a complete history, chronologically arranged, of all adjustments, repairs, and replacements made to or on the engine, and all authorized modifications embodied. The daily and other periodic examinations made must also be recorded, and all entries certified by the ground engineer by whom, or under whose supervision, such work was carried out.

All entries must be clear, concise, and written in ink.

The pages of the log book on the left hand side are ruled for the entry of dates, the speed at which the engine was run, duration of running, and times run since last top and last complete overhaul. The right hand pages are for the entry of particulars of adjustments made and the details of replacements and overhauls.

All entries are required to be made within twenty-four hours of the events to which they refer—in practice they should be made the same day as a particular job is completed.

AIRWORTHINESS HANDBOOK FOR CIVIL AVIATION

Another publication with which all ground engineers must be familiar is the *Airworthiness Handbook for Civil Aviation*, Air Publication 1208

(herein referred to as A.P. 1208), also obtainable from His Majesty's Stationery Office.

The handbook supplements and amplifies the requirements, both technical and legal, of the Air Navigation Directions. It is published in the form of a series of leaflets dealing with design, manufacture, safety requirements, inspection, etc.

Additions and amendments to this handbook are notified periodically by means of a notice to aircraft owners and ground engineers.

Many of the leaflets are admittedly of small value to the average ground engineer, but a large percentage are of vital interest and concern, and their contents must be thoroughly understood by him.

TECHNICAL KNOWLEDGE REQUIRED BY CANDIDATES

The details of the technical knowledge required for a "C" licence are briefly set out in the Air Ministry pamphlet No. 34. A copy of this pamphlet is forwarded with the official application form to all new candidates, and it is on this pamphlet that candidates will eventually be examined by the Board of Examiners at the Air Ministry.

It should here be noted that "C" licences are not issued to cover all types of engines, but only such named types of which the candidate has proved to the satisfaction of the Board that he possesses the necessary experience. Exception to this will only be made in very special cases, e.g. if a candidate should satisfy the Board that he has a very sound and thorough knowledge of the principal types of modern radial engines and has also had a fair experience of one or two types of the small 4-cylinder vertical engines, he might be recommended for a licence to cover "all air-cooled engines," but it must be again emphasized that such a recommendation is exceptional.

New candidates are strongly advised, when completing the official application forms, to review carefully their experience and only include those engines upon which they are certain they can satisfy the examining board. They will be given every opportunity during the examination of amplifying the statements made in the application form, and they are advised to omit any reference to engines on which they have had only limited experience until they appear before the board and trust to the mature judgment of the latter to make their recommendations as wide as possible.

By adopting this method the candidate will inspire greater confidence in the board, who will in consequence give him more sympathetic consideration than they would to one who assumes to have a wider knowledge of the subject than his examination proves to be the case.

The subjects will now be dealt with in the same order as they appear in the pamphlet (A.M. 34).

(*I*) *Knowledge of the general construction of the particular type or types of engine for which the licence is required, together with the running permissible before overhaul. The method of carrying out top-overhaul, allowances for wear and distortion. The methods of inspection and testing during and after top-overhaul to ensure correct assembly and functioning.*

Candidates must be able briefly to describe the essential details of construction of the engine(s) he desires to have included in his licence, referring to any special features in design and/or construction—e.g. any features which entail unusual methods of fitting, assembly, or maintenance. He must also be able to describe, and, if required to do so, roughly to sketch the lubricating systems of each and every engine, from the tank (or sump) through the whole system and engine back to the tank (or sump), also the method of lubricating all parts supplied from an external source.

He must also satisfy the board on having had the necessary experience, both in the workshop and on the aerodrome, on general workshop processes and in the repair and maintenance of the engine(s), and that he is familiar with the recognized maximum period it is safe to run the engine(s) between the top and complete overhauls.

In this connection candidates are reminded that the ground engineer is solely responsible at all times for determining when an engine requires attention and the amount of work to be done and replacements necessary to maintain it in an airworthy condition. Engine makers invariably recommend maximum periods for both top and complete overhauls and these periods should not be exceeded to any appreciable extent unless the ground engineer is quite satisfied from the general running of the engine that the times so recommended can be exceeded with safety. In permitting such an extension he must make quite certain that revolutions, oil pressure, consumption, and all other indications as recorded in the log book are beyond suspicion and justify his decision.

Should he permit an extension, or should he in fact allow the engine to run at any time when the log book entries indicate that the engine is not maintaining power or is otherwise in an unsatisfactory condition either internally or externally, he is liable to be severely censured by his supervising authority, and any repetition of this failing would most probably result in the cancellation of his licence.

The method of carrying out a top-overhaul involves the question of the extent to which a "C" man may dismantle an engine and the operations he may undertake. Generally speaking, it is taken that he may dismantle an engine as far as possible without disturbing the crankcase joint, or interfering in any way with the main and big-end bearings. For the rest he is permitted to carry out minor repairs and/or to replace any part found to be worn or damaged providing that such parts are obtained from an approved source, duly covered by the necessary documents as laid down in Section II and Section V of the A.N.D.

The extent of dismantling of magnetos is also limited, and is confined to taking down distributors, contact breakers, brushes, etc., and the cleaning, adjusting and/or replacement of these, or parts thereof.

The candidate must also be able from experience to detail the main points where defects may develop and his method of rectifying same. He must be able to express in general terms the allowances that may be made for wear and distortion. On this point candidates are not expected to be able to recite to the last thousandth of an inch the engine makers' recommendation for a particular dimension. He must, however, satisfy the board that he possesses either a copy of the engine makers' handbook containing this information, or his own notebooks in which these particulars are detailed.

Systematic reference to a reliable note or handbook will invariably result in a more satisfactory job than trusting to memory.

The inspection and testing referred to in this paragraph of the syllabus relate to individual components and not to the completed engine. They include pressure testing water-jackets and other parts of water-cooled engines; air pressure of induction systems and the rectification of faults found; testing the bores of cylinders, pistons, etc., for ovality and/or distortion; testing gudgeon pins, bores of pistons, and small end of connecting rods for parallelism and alignment; testing valves, after grinding in, for being gas-tight, etc., etc., besides a thorough and minute examination of every part as they are built up to ensure correct assembly.

(*II*) *Knowledge of the methods of examining and testing the correct erection of the power plant and its accessories in the aircraft, including*

the fuel, oil, cooling, ignition, induction and exhaust systems, tanks and pipe lines, engine controls, airscrew complete with hub, together with characteristic defects.

It must be realized that the work covered by the "A" and the "C" licence overlaps when installing an engine in the air-frame. Although it is fundamentally the duty of the "A" man to ensure that the engine bearers are true and in accordance with rigging instructions it is also the responsibility of the "C" man to ensure that this has been done before he attempts to install the engine.

He is also responsible for all services to the engine, including tanks and pipe lines for fuel, oil and water, and for ensuring that the supply from these is requisite for the engine's requirements, that all engine controls, including those for magneto and throttle, function correctly, are free of excessive backlash, and well lubricated.

He must also ensure that all ignition wiring and switches are sound and function satisfactorily, that the induction and exhaust systems are correctly assembled and properly stayed, and all joints gas tight. The assembly of the airscrew to its hub and the fit of the hub on the airscrew shaft are also the responsibility of the "C" man.

(*III*) *Knowledge of the inspection, adjustment, and testing of the power plant and its accessories to ensure correct functioning and power output after installation in the aircraft and during daily maintenance including airscrews, magnetos, carburettors, pumps, filters, engine starters, and starting mechanism and other parts or components on whose condition the correct functioning of the power plant depends.*

Regarding the testing of engines after top-overhaul, while some form of variable torque dynamometer is preferable such apparatus is not always available. Recourse has therefore to be made to a test or calibrated airscrew. The use of the ordinary flight airscrew for testing is not satisfactory for the reasons given further on in this book in the section dealing with engine testing.

A candidate will be required to show that he has a practical knowledge of the principles of tuning up, and to describe the principal defects arising from faulty carburation, incorrect magneto timing, also the evidence and method of tracing and remedying defects in all accessories with which an engine may be fitted.

He will also be required to outline in some detail the normal routine inspection he would subject an engine to, calling on his experience where he has found some peculiarity on a particular type of engine that calls for more than ordinary attention.

Where starters are fitted, he must know what type or types have been approved for a particular engine, and be able to describe their functioning and method of testing. He must also be familiar with any types of auxiliary pumps and similar accessories that have been approved for a particular engine.

(*IV*.) *Knowledge of the methods of inspecting and testing the installation of the instruments connected with the power plant concerned, to ensure correct functioning, including pressure gauges, temperature and revolution indicators, boost gauges, and tank contents gauges.*

Candidates must have a general knowledge of the construction, functioning, and installation of the instruments referred to above. While some knowledge of the methods of testing as applied in the laboratories of the instrument makers is an advantage, it is not essential, since the candidate is unlikely to have the elaborate plant at his disposal necessary to carry out such work. He is therefore limited to comparing the performance of a

doubtful instrument against one of known accuracy. A candidate must, however, be familiar with all the special requirements and precautions necessary when installing these instruments.

(V) For licences to include supercharged engines, a knowledge of the functioning of superchargers and boost control is required.

As is indicated from the wording of the syllabus, this subject is only taken where the engines required to be included in the licence are of the supercharged type.

To be successful, the candidate must give proof of having a detailed knowledge of the principles of supercharging, the construction of the particular supercharger and the methods of testing an engine so fitted, and it is also desirable that he has a knowledge of the special test equipment which is necessary.

He is required to have a knowledge of the method of control and adjustment of boost pressures and of setting and adjusting the throttle and gate control during the installation of the engine in the machine.

(VI) For licences to include compression ignition engines, a knowledge of fuel injection systems and methods of regulation is required.

This also is a special subject and examinations at the present time are largely confined to named types of engines only, but a general knowledge of the principles of compression ignition with some knowledge of the fuels used and the method of starting are essential.

In conclusion of this part new candidates may rest assured that the examination will be confined normally to practical points and subjects only. A working ground engineer is not expected to be fully conversant with either aerodynamics or the theory of internal combustion engines. His job is to repair and maintain, not to design, although at the same time some sound knowledge of theory frequently assists in solving practical problems.

PRACTICAL HINTS ON OVERHAULING, INSTALLING, AND MAINTAINING AERO-ENGINES, AND OTHER POINTS COVERED BY GROUND ENGINEERS' LICENCES IN CATEGORY "C"

1. REPAIR AND OVERHAUL

Cylinder Heads (Air-cooled Engines)

These components require very special attention, particularly where made of cast aluminium alloy with valve seatings of bronze or steel, either pressed, cast, screwed and/or expanded into the head casting. These seatings have a tendency to work loose and a constant watch must be made for the first evidence of this happening. They must, therefore, be tested whenever the head is removed. There are several ways of testing—e.g. a light tap on the under-side (care being taken not to bruise the seat face) will, if the seating has started to loosen, result in an oil stain appearing in the carbon at the joint between the seating and the head. (This test must, of course, be carried out before decarbonizing.) An even more searching test can be made when testing the effectiveness of the valve grinding operation referred to later.

The defect is one that develops fairly rapidly once it has started, and unless attended to immediately will most probably result in a serious breakdown of the engine.

The only remedy is to fit a new oversize seating. This, as a general rule

can only be carried out by the engine makers, who alone have the necessary special tools that are essential.

Some designs also include inserted bronze sparking plug bosses. These must be watched and treated in precisely the same way as the valve seatings and must be regarded as of equal importance owing to the dangers of air leaks and consequent overheating.

After thoroughly cleaning all over, examine for cracks, particularly around the inlet and exhaust parts, bosses for holding down bolts, valve rocker brackets where cast integral with the head or of the webs supporting the platforms or other seating where the brackets are separate.

Should any of the fins be cracked or broken, an effort should be made in the former case to localize by drilling a small hole at the end of the crack. If impossible owing to position, it is better to break away a small portion of the fin and smooth up the edge. The removal of a small portion of one or two fins will not seriously affect the efficiency of the cooling.

Examine all the jointing faces and/or spigot joint to cylinder for distortion, true up where necessary.

Examine all studs for fit of thread in the head; any that are found to be at all slack must be replaced by ones having oversized threads.

Examine valve guides for wear especially for being excessively bell mouthed at either end and/or burnt at the inner or combustion chamber end.

Replace where necessary, using proper tools, if only of the bolt and tube type. On reamering out the bore of the new guide, make sure that the reamer is truly square with the valve seat.

(Note. Where a new guide has been fitted, it is a good plan to use a little plumbago and oil as a lubricant on assembly. This will prevent any tendency to "picking up.")

If the valve seat requires re-cutting, ensure that the cutter is square with the valve guide.

Where there is any pocketing resulting from the valve having hammered into the seating, the ridge must be removed by blending the seating, using a rose cutter having a greater cutting angle than that of the valve seat. Unless this is done, the sharp edge made by the pocket will eventually cause pre-ignition, with all its attendant evils of overheating, burnt valves, etc.

When grinding in valves on to bronze seatings, use a very fine grinding medium. The ordinary paste is liable to cause circumferential grooves which frequently can only be removed by recutting the seat. Even with a fine medium, pressure at first, and until the "edge" has been taken off the grinding medium, must be very light.

Finish with metal polish to get a really first-class joint.

To test, assemble valve with springs, etc., and pour a small quantity of petrol through the port on to the top face of valve and examine the underface. A little chalk rubbed on the seating will assist in showing up any tendency for the petrol to percolate through. Incidentally this test, where the head is of the type referred to previously, will also show up any slight tendency for the valve seating to start loosening. Avoid the obvious error of mistaking one defect for the other.

Examine all parts of the valve rocker mechanism. Where adjustable pads are fitted in the end of the rocker—they are generally case-hardened—ensure that they are not cracked, that there are no flats or that they have not worn through the "case" and are in consequence soft. Where the rockers are operated by push rods through a ball joint see that the wear in the socket is even and is not causing binding at any point in the cycle of operation.

Thoroughly examine the brackets supporting the valve rockers for cracks and excessive wear. In particular see that the fulcrum pins are a good tight fit in the bracket and have no excessive clearance in the rocker, or *vice versa*, where the pins fit into rockers and float in the brackets.

Cylinders (Air-cooled Engines)

Until a few years ago, cast iron cylinders were fairly common on the smaller low-powered engines. Such cylinders require special attention, since they are liable to develop cracks in the fins, and should be examined very closely for this defect.

The only remedy that can be applied is that referred to above under Cylinder Heads.

On more modern engines of this type and on the larger engines steel cylinders with the fins machined from the solid are invariably fitted. Apart from mechanical damage, and the possibility of cracks developing from bad machining at the root of the fins, few troubles should be experienced.

Examine all joint faces and remove all bruises, at the same time maintaining true surfaces. Examine bores for scores, uneven wear, including ovality. Where scores are not too deep, remove by light lapping, but where this is impracticable, they must be returned to the makers or other works where they have the necessary facilities for regrinding.

Cylinders (Water-cooled Engines)

Most modern water-cooled engines are fitted with cylinders of the mono block type with the water jackets cast in a light alloy, and steel liners pressed or screwed in or located by some special form of jointing.

There are still in service, however, types of engines in which the water jacket of each separate cylinder is built up from steel sheet.

Water leaks are probably the greatest of the troubles experienced on these components and each type of cylinder requires different treatment in remedying the defect.

Leaks due to corrosion of the liner are less frequent in the more modern engines due to the liners being treated before assembly by nickel deposition or other protective methods. On the older types, however, this was a very real difficulty, and in the case of those with built up steel jackets resulted in scrapping the entire cylinder.

The repair of leaks in the jacket is more simple. In the case of the cast jacket plugging is the best method, while with the built up steel jackets the trouble can be overcome by sweating a small piece of light gauge sheet brass or copper over the defect. Great care must, however, be exercised in carrying out this operation in order to avoid distortion, and only a reasonably light tinman's soldering iron should be used for this purpose. Under no circumstances use a blow lamp, however small in power, as irreparable cracking of the water jacket is likely to result from stresses set up in the metal from local overheating. For this reason welding or brazing must not be attempted.

Water leaks may also develop in the joint between the liner and the cast jacket which necessitates in many cases a fair amount of dismantling in order to remedy the defect. Care is necessary during reassembly to ensure correct alignment of all parts and to avoid distortion which may impose undue stress in the jacket or adjacent parts.

The whole of the water cooling system should be tested at every overhaul. The pressures to be used and the exact method of carrying out the test vary to some extent with different types of engines. In general they include a test with hot water at a pressure up to 40 lb. to the square inch,

followed immediately by a similar test using cold water. The makers' instructions in this respect, however, must be strictly followed in every case.

Examination of the valves, etc., will be made in the same way as on air-cooled engines, but the design of the valve gear invariably includes a camshaft running the entire length of a cylinder block and in some designs two or more blocks. Bearings for the camshaft may form an integral part of the cylinder head or may be mounted in a separate case, which in turn is mounted over the cylinders.

In the latter type great care is necessary in lining up the bearing face(s) on which the camshaft casing is carried, and any low points must, where the design permits, be made up by inserting shims of the requisite thickness or by truing up as the case may be. The under-face of the case must also be checked and trued up where necessary.

Failure to observe these precautions will probably result in a failure of the cam casing due to the development of cracks.

The lubricating system also calls for special attention, all oil holes and channels must be cleaned and examined to ensure that all parts of the cam and valve gear are properly lubricated.

Examine all cams for wear and remove any scores by light stoning. If flats are found in any of the cams test with a smooth file to ensure that wear has not progressed through the hardened surface. Replacement of the entire camshaft is the only cure for this defect, but if still hard, stone down any ridges formed adjacent to the flats to ensure smooth working of the valve gear.

Examine all studs for damaged threads and also for slackness in the housing. In the latter case replace with studs having oversize threads on the end fitting into the housing.

All gears must be examined for wear and damage and adjusted to give the clearance and backlash recommended by the makers.

Examine all splines or other method of joining up the sections of the cam driving shafts. Replace where excessive wear or damage is found. Smooth out any sharp nicks which may lead to the development of cracks.

Valves

Remove all carbon, and examine stems, grooves or thread for the spring retaining collets or valve ends. On some engines the makers call for special fits at this point; ensure that these requirements are met. Examine the valve end for wear. Many modern designs include a detachable valve end which makes replacement for wear a simple matter, but where no such provision is made the end of the valve must be dressed up where necessary in order to present a true face for the valve operating gear. The seat of the valve calls for minute examination for cracks, in addition to evidence of burning. Cracks may also be present at the base of the stem where the latter blends into the head. Lightly polish out any scores on the stem.

Valve Springs

Clean and examine all over for signs of cracks and at the ends for uneven wear and for damage.

Check for tension or rate of loading and for "free" length. Failing better facilities a good idea of tension can be obtained by compressing a new and a worn spring by hand. Any serious difference will be readily noted. For "free" length also compare with an unused spring where the drawing dimension is not known.

Pistons

Clean the carbon from the crown, ring-grooves, particularly at the back of the latter, all oil holes and inside of the crown. When cleaning the ring grooves be careful not to damage the sides or uneven ring float will result.

Next examine all over for cracks—the most likely place for this defect to develop is at the junction of the gudgeon pin bosses and sides of the piston; from any of the oil holes, in webs supporting the crown and/or gudgeon pin bosses, from a bruise or other damage on the bottom of the skirt. Remove any deep scores on the skirt but do not bring the piston outside the limits for ovality.

Check the bores of the gudgeon pin bosses for wear and also for alignment, and for being square with the sides of the piston. To do this place the piston, head downwards, on a surface plate, check the sides for being square, allowance being made for the fact that the diameter varies, being larger at the bottom than at the top. Place a mandrel a few thousand smaller than the gudgeon pin through the gudgeon pin bores, check by means of a clock dial indicator. 0·001 in. per inch length is the usual error allowed. Check the outside diameter for size and also for ovality.

Where it is necessary to replace a piston, ensure that the new one is of the same weight as the old one in order that the dynamic and static balance of the engine is not disturbed.

Piston Rings

Clean all over including any holes that may be drilled in scraper rings.

Examine all bearing surfaces for wear. Check the free and working gap. For the former lay the ring on a surface plate, and in the absence of drawing dimensions compare with a new ring.

For measuring the working gap insert a piston (on which a small quantity of thin oil has been smeared) about $\frac{1}{3}$ up the working stroke of the cylinder to which the ring is to be fitted.

Insert the ring in the mouth of the cylinder and gently press up against the piston, thus ensuring that the ring is square, then push the piston clear of the ring, care being taken not to disturb the latter. An accurate measurement of the gap can now be taken with feeler gauges. Refer to makers' handbook as to the range of dimensions that can be allowed for the gaps.

No general figure can be given since they vary considerably, one maker restricting the greatest gap from 0·006 in. to 0·008 in., while another maker will allow 0·015 in. to 0·016 in.

Next check the float of the ring in the groove from which it was removed and to which it will again be fitted.

On most engines the float varies on the different rings, being greatest on the top one, the remainder having a progressively smaller float. Here again actual dimensions vary on different engines, but on most modern engines it is usual to allow about 0·010 in. to 0·012 in. for the top ring and 0·006 in. to 0·008 in. on the lower one. Dimensions for both float and gap also vary in many cases as between gas and scraper rings, and the engine makers' handbook should be consulted on this point.

Gudgeon Pins

These parts are generally made from case-hardened steel and cracks are liable to develop should there be any flexing when the engine is running; therefore, after thoroughly cleaning they should be very carefully examined for this defect. A good light is essential, as in the initial stages this defect is very difficult to detect. Measure for wear and for being parallel.

If pads are fitted for locating the gudgeon pin, ensure that they are a snug fit in the ends and are not unduly worn. Where location is by means of circlips examine the grooves for signs of cracks or other damage. A slot for assisting in the removal of the circlip is also provided in some designs. The corners of such slots must be examined for possible cracks.

Connecting Rods

Beyond an examination of the small ends and ensuring that the big end bearings and wrist pin ends are not unduly slack there is little that the "C" man can do. Of course, if any defect is discovered in the big end or wrist pin ends, the overhaul becomes a complete one, and must be handed over to a ground engineer holding a "D" licence for the particular engine.

If satisfactory, proceed by checking the bores of the small ends for wear and alignment.

Errors of alignment comparable with those referred to above for gudgeon pin bores in the piston can be permitted, and the method of measuring is the same except that the cylinder jointing face of the crankcase is used as a base instead of a surface plate.

Clean and examine all oil holes and/or grooves.

Crankcase

Examine the jointing face for cylinders and clean up where necessary. Beware of cracks which frequently develop from holding down studs. Some makers permit a limited number of these cracks without scrapping the crankcase. Where several cracks are found, ascertain the makers' recommendations in this matter before proceeding further. Examine all studs for damaged threads and for being slack in the case. Where any are found, they must be replaced by studs having oversize threads in the end that screws into the case.

The interior of the crankcase must be examined, particular attention being paid to all split pins, circlips, and/or other locking devices to ensure that all parts are properly retained.

The examination should, where possible, cover all ball or roller bearings to ensure that these are not spinning in their respective housings. Attention must be paid to all supporting webs, especially those for the main bearings. Flush out all oil ways and leads, and where internal oil galleries are fitted examine all joints for possible failure. On those engines where the camshaft is housed inside the crankcase, examine all cam profiles for wear and damage, also the train of gears by which it is driven.

Many engines are now fitted with a small diaphragm type petrol pump which is driven by a cam, sometimes included on the main camshaft. The diaphragms of these pumps have a definitely limited life and must be renewed from time to time in accordance with the maker's instructions. At each overhaul all other working parts must be checked, new diaphragms fitted where necessary or where nearly due for renewal and the reassembled pump checked for efficiency. A diaphragm must be regarded as a vital accessory of the engine, failure of which would most probably have serious results.

Carburettors

Completely strip down and examine all parts. Check the toggle gear and replace any parts that are worn. Examine the float for punctures.

The best way to do this is to immerse the float in boiling water for a

few minutes—if punctured the escape of the expanded air will show up very quickly and the puncture located. Any attempt to repair entails great care. The lightest of soldering irons must be used, and only the smallest quantity of solder used that will suffice to stop the puncture.

Examine the seating of the needle valve and grind in. Where needles and/or seating are of bronze use metal polish as the grinding medium or razor paste where of stainless steel.

Check and adjust the petrol level before assembling on to the engine; this saves a lot of time in the subsequent tuning up.

Magnetos

Ground engineers, excepting those holding the special "X" category licence, are strictly limited in the amount of work they can undertake in the matter of overhauling of magnetos, and must confine their efforts to cleaning, adjusting, and replacing the smaller components.

The contact breaker, distributor, and brushes should, however, be removed, cleaned with a cloth soaked in petrol, and examined for wear. Examine the contacts of the contact breaker and, if dirty or worn, clean up with a piece of very fine emery cloth, being careful to clean away all dust resulting therefrom.

Examine the movement of the bell crank lever carrying the contacts—see that the bearing is free in its bush and lubricate with a smear of light oil. Be sure that no oil is allowed to collect on the contacts or when this oxidizes the efficiency of the magneto will be greatly impaired. On re-assembling the contact breaker on its shaft, make sure of correctly locating it on its key or other means of location.

Examine contact gap and adjust where necessary to 0·012 in.

Most of the present day light aero-engines have one of the magnetos fitted with an impulse starter. Extra precautions are necessary when assembling this to the engine; first in regard to the timing and secondly as regards position.

With reference to timing it is necessary to set the impulse mechanism in its correct relationship to the armature.

Markings are usually provided on the driving and driven members to assist but in case of doubt the magneto makers' instructions on this point must be ascertained before finally locking up. No definite instructions can be given here as the actual settings vary on the different types of magnetos, and also on the different types of impulse starter mechanisms.

On the second point it is important that no end thrust is imposed on the impulse starter mechanism when fitting the magneto to the engine. Unless this precaution is taken there is a danger of the impulse binding and ceasing to function. Even with the comparatively soft serrated rubber compound form of drive so frequently used a definite although small clearance is essential between the two elements of the drive.

Airscrew Shafts

The makers of some geared-engines recommend definite periods of overhaul for the airscrew shaft component—such periods approximating that of top-overhaul of the engine. The following are the main points that must be attended to—

All gears must be closely examined for wear and damage and must also be checked for backlash with the mating gear or gears. On simple reduction gears where the loading is very heavy the makers sometimes lay down very close limits for eccentricity of backlash—i.e. the maximum and minimum backlash recorded on a given number of measurements taken

on one complete revolution of the larger gear must be within, say, 0·003 in. to 0·006 in.

Any serious excess of the actual figures laid down by the makers results in excessive loads on the gears at those points where this excess exists and failure of the gears may result.

Should it be found necessary to replace a gear it should be remembered that many engine makers now match up important gears in pairs or sets, which in turn necessitates their replacement in pairs or sets. Where only one gear requires to be renewed, however, as a measure of economy, the matter may be referred to the makers, who may be able to match up a new gear to the existing good one(s).

All ball or roller bearings must be examined for wear not only for the balls or rollers and/or their tracts, but also to ensure that both inner and outer races have maintained the required fit on the shaft or in their housings, and replaced where found to be slack in their housings.

On most modern engines it is usual to provide spare bearings oversize on outside diameter of the outer race, so there should be little difficulty regarding spares. Where the inner race is slack, metal depositions of the shaft will overcome this trouble.

The airscrew shaft should be checked for truth by mounting on vee blocks on a surface plate and checked by means of a clock dial at the endmost plain portion of the shaft. An indicator figure of about 0·003 in. to 0·004 in. is generally permissible, but should not be exceeded to any great extent or vibration will result.

Examine all key-ways and/or splines for wear and fit with their mating parts. Should any sharp "nicks" or bruises be found, these must be carefully blended out. Remember, abnormal stresses are liable to concentrate at such points and will probably result in a fatigue fracture.

This point should, therefore, receive close attention whenever an airscrew is replaced or refitted.

2. INSTALLING THE ENGINE INTO THE AIR-FRAME

As previously stated the duties of the "A" and the "C" category ground engineer overlap to some extent at this stage, in that the "C" man must ensure that the engine bearers are fit in every way to receive and accommodate the engine. Having visually examined for damage and checked for truth he can offer up the engine but before any attempt is made to bolt down, each and every bearer or foot, in the case of a vee or vertical engine, must be checked by feeler gauge to make quite sure that all are bearing equally on their respective supports.

Should a gap be found at any point where a bolt is fitted, aluminium packing washers of the requisite thickness must be inserted. Unless this precaution is taken, failure of the crankcase may result.

Where rubber bearer blocks are fitted special attention must be paid to these to ensure that the rubber is not perished and has retained its required degree of resilience.

Similar precautions are necessary in the case of a radial engine, excepting that the fit of the spigot is of importance as well as the accuracy of the fit of the case to the bearer plate.

Having satisfied himself on this point the engine may now be bolted down, after which he may proceed with the connecting up of the fuel, oil and water supplies, switch wires, etc. Before doing so, however, he must ascertain by actual test that the supply from these services is adequate for the requirements of the engine.

Starting first with the fuel service, examine the tank and ensure that the interior is perfectly clean and free from corrosion; thoroughly clean out the sump and filter and where of the gravity feed type do not overlook the small hole in the vent. Should there be any doubt on the soundness of any joints the tank should be submitted to a pressure test. To do this fill the tank to about one-third its total capacity with either petrol or paraffin (the latter for preference, but ensure that all traces of this are removed after the tank has been tested). Then paint over all joints with a mixture of whitening and water or methylated spirits, and when this is dry apply air pressure but do not exceed that quoted in leaflet D.3. of A.P. 1208. The tank should now be moved about so that its contents cover all joints in turn.

The pipe lines must next be closely examined throughout their entire length.

Where of copper tube closely examine for cracks, remember that copper tends to crystallize when subjected to vibration over a length of time. Where the pipe is a flexible one, examine for signs of disintegration of the component materials, generally evident by blistering.

Before connecting up to the carburettor(s) check for flow; this should be carried out by means of a calibrated measure (not less than one gallon but preferably two gallons) and a stop watch.

The flow must be 100 per cent *in excess* of the maximum required by the engine. When making this test the tank should contain 10 per cent of its capacity, and the machine should be in the position giving the lowest head on the fuel supply. (See leaflet D.3 of A.P. 1208.)

If this flow is not obtained recheck at the next joint and so on until the obstruction is found. Clear or replace the pipe as may be necessary. In cleaning out a pipe great care must be taken in the selection of the material used for cleaning. Anything in the nature of very soft fabric must be avoided since a certain amount of "fluff" is sure to be deposited in the pipe which will eventually find its way to the filter and in time choke it. A small, stiff, bottle-washing brush is the safest means of effecting this cleaning. If the obstruction cannot be entirely removed the length of pipe affected should be replaced.

Where a dry sump engine is fitted examine oil tank and pipe line. Ensure a full bore flow of oil from the union before connecting up, not only as a check for supply, but also to avoid air locks.

Similar action should be taken with the water service where applicable.

Connect up and check all ignition wiring, both for continuity and for insulation—the former by means of a bell or lamp and battery, and the latter by a megger.

In connecting up the switches remember that they work in the opposite way to the household lighting or power switch, in that when the bridge is closed the magneto is "dead" from the fact that by closing the circuit we divert the current from the primary circuit of the magneto to earth.

The official requirements as to fitting these switches are contained in leaflet D.1 of A.P. 1208.

The induction pipes can now be fitted. Ensure that all joints are airtight otherwise weak mixtures and consequent overheating of the engine will result. Some engine makers call for a smoke test for this purpose. It is preferable to leave the fitting of the exhaust manifold until after the engine has been tuned up in order that the characteristics of the exhaust flame may be observed.

Before any cowling is fitted all controls must be closely examined joint by joint as well as for correct functioning.

Every joint must be examined to ensure that all pins, etc., work freely, but without undue slack, and are properly lubricated. For the official requirements regarding the correct functioning of controls see design leaflet D.1 of A.P. 1208.

The cowling may now be fitted and finally the airscrew. Before fitting the airscrew examine for defects, including signs of the lamina opening up, also for damage at the tip caused by stones, etc. Where any repairs are necessary it should be re-balanced before fitting.

3. TESTING THE ENGINE AFTER TOP-OVERHAUL

(Normal Aspirated Engines)

It will be noted that the "C" leaflets of A.P. 1208, which deal with the requirements regarding the testing of aero-engines for civil aircraft, do not lay down any tests in the case of top-overhaul. The extent of testing required is left to the discretion of the ground engineer and is dependent on the amount of work done and the relative importance of any parts replaced during the top overhaul.

All tests should, however, be made with a calibrated test airscrew or one of known value.

Where no replacements of importance have been made and the test is, therefore, one to prove assembly only, it may be carried out with the flight airscrew, providing it is the same one that was fitted when the power of the engine was known. This is an important point, since it must be realized and appreciated that no two airscrews, although made from the same drawing, have precisely the same characteristics, due to the necessity for having manufacturing tolerances.

While such tolerances are kept as fine as is practicable from the manufacturing standpoint, it is an established fact that a difference of over 5 per cent in power absorbed is not unreasonable.

Take, as an example, two airscrews for an engine having a normal speed of 2,000 r.p.m. The "revs." on the ground would be of the order of 1,800 to 1,850 with an average airscrew, but owing to the fact that each airscrew happens to be on the opposite extreme of the tolerances, it is possible that one will give 1,780 r.p.m. and the other 1,900 r.p.m.

Supposing the heavy one, giving 1,780 r.p.m., had been fitted originally, but on the test after overhaul the light one was fitted and the engine gave 1,800 to 1,820 r.p.m., the engine would probably be passed as up in power, whereas it is in fact low in power. Conversely, if the light one had been fitted originally and the heavy one fitted for the test in question, the engine giving 1,820 to 1,840 r.p.m., it would most probably be turned down, but in this case it is actually up in power.

The futility of trying to assess power by means of an uncalibrated airscrew is therefore apparent.

Test airscrews are designed to absorb approximately 90 per cent of the rated power of the engine at normal or international r.p.m., and by the cube rule will hold the engine to within about 5 per cent of maximum permissible r.p.m. at full throttle. They thus permit the full range of the tests to be run.

Another point of importance that must be considered is that of cooling, particularly where air-cooled engines are concerned, since we are dependent upon the slip stream from the airscrew to maintain within reasonable limits the temperature of the engine while running on the ground.

Here again there are fundamental differences between test airscrews and those used in flight. In the former the slip stream flows back right over

the engine and effectively cools it, whereas with the flight airscrew, the flow of the slip stream is much wider and little if any is directed over the engine. "Flight" airscrews are therefore quite useless for prolonged running on the ground.

If, in extreme cases, it is quite impossible to obtain a test airscrew, and providing the replacements of major parts have been negligible, it may be permissible to run the engine on the ground with the flight airscrew to ensure that it is giving reasonable power, and to follow this by a short flight, when the power of the engine may be judged to some extent by the performance of the aircraft.

Similar procedure will have to be adopted where the original flight airscrew has become unserviceable for any reason.

We come now to the actual testing. The ground engineer responsible for the overhaul must decide the extent of this, and he must be guided by the amount of work done or number and relative importance of the replacements made.

If, for example, no major parts have been renewed, there is no necessity to strip the engine following the duration test; but if one or more pistons, or equally important components, have been renewed, it becomes essential to strip the engine to ensure that the new part is satisfactory.

In the former case (no major renewals) a run of half an hour at normal or international r.p.m. (assuming a test airscrew is used) terminating with two minutes at full throttle will suffice; whereas in the latter case (where important components have been renewed), the test should be not less than one hour exclusive of any period "running in," again opening up for the last two minutes to full throttle, followed, after an examination of the renewed parts, by a further run of 15 minutes, the last two of which must be at full throttle.

We now come to the actual procedure for running the test. Having examined every part to ensure that everything is properly locked and that the tanks have been filled with the approved fuel and oil, the engine may be started up and run at its lowest speed, which should be at about 400 r.p.m. Observe the oil pressure closely. This should drop very gradually as the oil becomes warm, but should it drop suddenly or should there be no pressure recorded in the gauge, stop the engine and investigate the cause.

Assuming, however, that the pressure is satisfactory, gradually open up to about half throttle and, with the engine running, go round to see that all external parts are working satisfactorily and that the distribution of the gas is reasonably even. Open out the throttle for a short burst and see that the engine will give its "revs."; but before proceeding with the test proper, shut down and go all round the engine and installation to make quite certain that all parts are quite tight.

Restart the engine and proceed with the tuning up. Open the throttle until the engine is running at or near normal r.p.m. See that it is running quite steadily, and that there is an entire absence of vibration. If this defect is present, trace the cause. This may be due to one or more of the following causes: the bearer bolts or adjacent parts being slack; the airscrew not being properly secured; incorrect mixture strength, or unequal distribution of the fuel; incorrect timing of either the valves or of the magnetos; local air leaks, etc.

Of these defects probably the most harmful is that of a weak mixture which, in addition to setting up vibration, causes overheating also. It is most readily detected (providing the test is being run at night, or in a subdued light), by examination of the exhaust flames. (It is here assumed that the exhaust manifold has not been fitted as was suggested earlier.)

The flame should be of a steady Bunsen blue. A weak mixture is usually denoted by the flames being short and of a green-blue colour, and a rich mixture by red flames smoky at the tip.

These colours do not, however, appear in the order given on all engines, and are only quoted here as a general guide. Experience on a particular engine is necessary before an exact determination of mixture strength can be arrived at by this means.

Uneven distribution should not arise if the engine has been correctly assembled, and if present will most probably be found to be due to an air leak at the joint between the cylinder showing the weakest mixture and the induction pipe or manifold. It may also be caused by excessive clearance of a valve in its guide or from a defective valve seating. Incorrect carburettor setting is another possible cause.

Finally, the airscrew may be the cause of the trouble. Having again made quite sure that it is properly secured to the airscrew shaft, check for accuracy of track of the various blades. To do this, from a point on the leading edge of one of the blades about one-third up from the tip, measure the distance to some convenient fixed and rigid point on the machine or test bed. Turn the airscrew until the next blade occupies the same position as the first one and again measure the distance from a similar point on the blade to the same point on the machine or test bed, and so on, until each blade has been so measured.

The difference in the measurements obtained gives us the amount the airscrew is "out of track." For an airscrew 6 ft. to 8 ft. diameter, this measurement may safely be $\frac{1}{4}$ in. to $\frac{3}{8}$ in. without causing vibration.

Having satisfactorily tuned up the engine, the correct independent functioning of each magneto must be checked by switching off first one and then the other and noting the drop in r.p.m. on each magneto.

The drop should not be more than $2\frac{1}{2}$ per cent, and must not exceed 5 per cent on most types of engines. This test should be repeated several times during the test of the engine.

4. SUPERCHARGED ENGINES

These engines are not at present in general use in civil aviation except by the larger operating companies, but this book would not be complete without some reference being made to them.

As far as top overhauls are concerned the work involved is largely the same as that on normally aspirated engines, except that we have to deal with the addition of the supercharge unit.

The ground engineer desirous of having this class of engine included on his licence or any engine to which a supercharger is fitted, is required to have a reasonable knowledge of the theory of supercharging; some experience of the special precautions necessary during testing and, in fact, during any running at sea level; and a detailed knowledge of the construction of the unit embodied on the engine or engines he wishes to have included on his licence. The following notes are therefore included as a guide to the new candidate and to those wishing to have engines of this type added to their licence.

Since the volumetric efficiency of all I.C. engines is largely dependent on the weight of the charge entering the cylinders, it follows that there must be a loss of efficiency of the engine as the aircraft ascends and the density of the air becomes less.

Supercharging was therefore originally applied to aero-engines for the purpose of overcoming this loss, and such engines had their power rated at a defined height above sea-level.

There have recently, however, been introduced supercharged aero-engines rated at ground level; supercharging in this instance being introduced for the purpose of giving additional power for take off and climb.

In both types supercharging is effected by the introduction of some form of compressor—generally a blower or fan—in the induction system, whereby the pressure in the latter is increased.

This blower is driven through gearing by the crankshaft, some form of clutch being embodied in the drive to absorb undue shocks resulting from acceleration and deceleration, the actual ratio of speed between crankshaft and blower being arranged according to the degree of supercharging required. This varies on different engines from slightly forced induction to what is known as "fully supercharged."

This increase of pressure in the induction system is known as "boosting," or boost pressure, and since it imposes increased stresses on practically every part of the engine it is vitally necessary that this pressure be confined, within certain limits, to that laid down by the engine designer.

The pressure in the induction system must therefore be constantly measured in the same way as that of the oil in the lubricating system of the engine. Due to the comparatively small but important variations of pressures (*absolute pressure as distinct from gauge pressure*) that have to be measured, the ordinary pressure gauge cannot be used for this purpose.

A special form of gauge known as a "boost" gauge is used instead. This, as explained further on in this section, is constructed on similar principles to that of an aneroid barometer, a type of instrument that is very sensitive to small variations in pressure, and compensates for variations in the atmospheric pressure.

The installation of these engines in an aircraft presents few difficulties not met with in the installation of a normally aspirated engine.

The real difference lies in testing after overhaul.

This we must consider under the two classes, viz. (1) those rated at an altitude, and (2) those rated at ground level.

The former class presents the greater difficulties, as special apparatus is required to test the engine for power after overhaul.

This apparatus includes a depression box fitted with adjustable orifices by means of which the air supplied to the carburettor may be maintained at a reduced pressure corresponding to the barometric pressure at a given altitude. Difference of pressure within the box and that of the air outside is measured by means of a mercury U-tube, and the figure at which this reduced pressure must be maintained is obtained by subtracting the barometric pressure at the altitude at which the engine is rated from the barometric pressure on the ground at the time and place the test is being run.

A thermometer must be fitted to the depression box in order that the temperature of the air within the box may be recorded, this being an important factor in the corrections that have to be made in the final calculations for performance.

The test is run on a calibrated airscrew and during the test observation must be recorded of the R.P.M., depression pressure, boost pressure and air temperature.

The normal power developed by the engine is obtained from the calibration curve of the airscrew. This must now be corrected for the various factors affecting engine performance.

These factors vary somewhat on different engines, and the reader is referred to the engine-maker's handbooks, which invariably include tables

of constants, and/or graphs, from which a finally corrected figure for performance is readily obtained.

Precautions have of necessity to be taken on all installations to prevent the possibilities of the engine being over "boosted," and the greatest danger of this occurring is at the moment of "take off" when the pilot's attention is fully occupied with other matters. A "gate" is therefore introduced in the engine controls which must not usually be passed through until the aircraft has reached a predetermined height above the ground.

The actual setting of this "gate" forms an important part of the duties of the ground engineer, since it must be so arranged that there is an ample margin of power for "take off" while at the same time the boost pressure must not exceed that laid down by the engine designer and approved for "take off" purposes.

This approved pressure varies on different engines and may be either rated boost pressure, or maximum permissible boost.

In setting the "gate" this point must be very carefully noted, and if in any doubt reference must be made to the engine log book.

Another point that must not be overlooked at this stage is the fact that the zero marking of the boost gauge represents normal atmospheric pressure at sea level at 15° C., i.e. 760 mm. of mercury or 14·7 lb.per sq. in., and a true zero reading will only be obtained when these conditions exist. The normal reading obtained will therefore be either plus or minus, according to the atmospheric conditions prevailing at the time.

Consequently, before the "gate" can be finally set reference must be made to a reliable barometer, in order that due allowance may be made for this variation of atmospheric pressure on the boost gauge.

Many of these engines are fitted with a device which automatically controls the boost pressure, thereby obviating the necessity for fitting the "gate." This generally consists of a servo motor controlled by an aneroid. The latter is contained within a casing which is connected to the induction system by a pipe. Any variation of pressure in this system causes the aneroid to expand or contract as the case may be. A rod is attached to one end of the aneroid which operates a valve which controls a supply of oil under pressure from the main lubricating system, to either the top or bottom of the piston of the servo motor. The piston, in turn, is connected mechanically to the throttle controls, and the pressure in the induction system is thereby maintained within predetermined limits.

An overriding device is embodied by means of which additional boost may be applied by the pilot for take-off purposes. A fuel enriching device is also fitted in some cases for the purpose of suppressing detonation at the higher boost.

These controls require to be very carefully maintained, as they are vital to the correct functioning of the engine. Owing to the many small but important variations in the actual adjustments necessary on the different types of engines, the reader is referred to the handbooks of the individual engines for details, and to treat the above notes as general only.

Coming now to the other class of supercharged engines, i.e. ground boosted types, the principal difference, from the ground engineer's point of view, is that they can be run on the ground at full boost, and that they obviate the necessity for fitting a "gate."

They must, however, be treated with the same care during installation and testing to ensure that they develop the necessary power without exceeding the boost pressure approved.

Further particulars on the adjustment of boost gauges, with tables

showing allowances to be made for variations in atmospheric pressure, will be found in Section 2, Chapter VI, of A.P. 1274.

5. THE ESSENTIAL INSTRUMENTS USED IN THE ENGINE INSTALLATION

Engine Speed Indicators

These instruments usually work on the governor principle, and consist of a central shaft, which is driven, either direct or through a gear box, at ½ engine crankshaft speed. Weights which are pivoted on this shaft tend to fly outwards by centrifugal force as the shaft revolves.

The movement of the weight moves a collar which slides on the central shaft and this movement is transmitted by means of a pinion and quadrant to the pointer moving over the dial. A spring is fitted which returns the weight to its normal position as the speed of the engine is reduced.

The instrument is connected to the engine or gear box by means of a flexible shaft. The latter is supported in a flexible casing, lubrication between the two being provided by an approved grease retained by asbestos packed casing.

The inner or driving shaft is fitted at either end with a solid connection of square sections which fit into a corresponding square hole in the engine, or gear box at one end, and in the instrument at the other.

When installing these instruments care must be taken not to make too many bends in the drive, and that no bend is less than 9 in. radius.

The average ground engineer generally has very limited facilities for testing this class of instrument, and can only make a comparison with another instrument of known accuracy. This should be done by means of a two-way gear box, driven by an electric motor the speed of which can be varied over a fairly wide range.

Alternatively the drive can be taken from the engine. The instrument of known accuracy should be connected to one of the dual drives and the one to be tested to the other. A direct comparison of readings over the range of the instrument can be made.

Pressure Gauges (other than Boost Gauges)

These all work on the Bourdon principle and consist of a bronze tube of oval section which is bent to form an arc. The tube is sealed at one end and open at the other.

The open end is attached to a union which is fixed to the case of the instrument, while the closed end is free to move but is connected by light link motion and quadrant to the spindle on which the pointer is mounted.

On pressure being applied to the open end, the tube tends to straighten, and in doing so causes the pointer to revolve over the face of the dial in proportion to the pressure applied.

The principal precautions to be taken on installing these instruments are, first to ensure that the service—oil,water, etc.—to be tested is actually reaching the instrument, and that there is no air lock or other obstruction in the pipe line of the particular service. For example, take the lubricating oil service.

Before making the actual connection between the service pipe and the pressure gauge, the engine should be turned a few times or until the oil begins to flow from the end of the pipe. It is also necessary to make quite

sure that a tight joint is made not only for cleanliness, but also to ensure that there may be no loss of pressure, and that the amount shown on the gauge truly represents the service concerned.

Testing is again, as a general rule, limited to a comparison with a similar instrument of known accuracy.

Make up a gallery of copper tube with three connections—two for the two instruments and the third for connecting up a pump. A comparison at two or three points over the range of the instrument should suffice to prove accuracy.

Temperature Gauges

These work on the same principle as the pressure gauges, and are of very similar construction except that the open or fixed end of the Bourdon tube is permanently fixed to a capillary tube of steel, copper, or copper-nickel, having a very small bore. At the other end of the capillary a length of brass tube or "bottle" is fitted. The latter is partially filled with ethyl ether or similarly volatile liquid, the remainder of the "bottle," the capillary tube and the Bourdon tube are filled with vapour from the liquid. On subjecting the "bottle" to any increase in temperature the vapour pressure increases through the whole system, and the Bourdon tube tends, in consequence, to straighten out in the same way as in the case of the pressure gauge. The dial readings of these instruments are therefore changes in pressures although calibrated in degrees of temperature.

Temperature gauges are also made in which the medium used for transmitting change in temperature is mercury instead of vapour pressure. This type of instrument is more accurate than those referred to previously.

In construction the principal difference lies in the Bourdon tubes, which instead of being a simple arc consist of several coils.

A simple check for accuracy can be made by immersing the "bottle" of the instrument in a vessel of water and gradually raising the temperature of the latter and comparing the readings of the instruments against those of an ordinary glass thermometer of known accuracy, placed as close as possible to the "bottle" in the water.

The water must be constantly stirred in order that its temperature may be equal throughout or serious errors in calibration may result from local hot spots in the water.

These instruments, especially where of the vapour pressure type, need to be handled with great care when installing to avoid damage, particularly to the joints of the capillary. This will result in an escape of the transmitting medium, which will be readily detected by smell. Damage to the mercury type will be evidenced by the escaping mercury which is under fairly high pressure within the instrument.

No attempt should be made to repair these instruments. Without the proper facilities and elaborate apparatus necessary for carrying out such work with any degree of success it is most probable that the attempt will result in irreparable damage being done to the instrument. It is more economical, therefore, in case of damage, to forward the instrument to some works having the proper facilities.

Boost Gauges

These work on the same principle as an aneroid barometer or altimeter in that they consist of a shallow corrugated metal box from which the air has been exhausted. Any reduction of pressure of the air on the outside of the box permits the latter to expand. This diaphragm movement is

transmitted through suitable mechanism to the pointer working over the face of the instrument which thus registers variations in pressure.

Their purpose is to measure the difference between the pressure of the air outside and that of the charge of gas within the induction chamber.

Actually the zero marking on the dial represents normal atmospheric pressure at sea level, i.e. 760 mm. of mercury or 14·7 lb. per square inch.

Figures on the right or in a clockwise direction represent increase of pressure while those to the left or anti-clockwise a decrease.

It must be fully appreciated that a true zero reading will only be obtained when the barometer stands at 760 mm. at the time and place the reading is taken, and that any variation in the barometer or in altitude will be reflected on the gauge reading being above or below zero, although the instrument is not connected in any way to the engine.

These instruments are generally marked to show the maximum variation in pressure for the particular engine to which they are fitted. When changing an instrument it is therefore important to note that this marking is correct for the engine to which it is now being fitted. Failure to observe this point and to fit an instrument incorrectly marked may result in the pilot over boosting the engine and possibly wrecking it.

Leaflet E.1 of A.P. 1208 details the requirements in connection with the installation. Reference should also be made to "Aircraft Instruments," by R. W. Sloley, published in this series; and to "General Instrument Equipment for Aircraft," Air Publication No. 1275, obtainable from His Majesty's Stationery Office.

6. GENERAL NOTES AND HINTS

The keynote of the ground engineer must be "system," for unless all his duties are carried out systematically, he is bound sooner or later to overlook some minor point that may result in a major defect arising. All duties should therefore be carried out to schedule, and these should be prepared for all phases of a ground engineer's duties.

As far as the overhaul of the engine is concerned, many of the makers include in their handbooks schedules for 10 hours, 25 hours, 50 hours, etc., examinations. These will form a good basis, to which must be added the many points peculiar to a particular machine or installation and the list of modifications referred to previously.

Apart from the value of these schedules to the ground engineer, the fact that his work is carried out systematically inspires confidence in the users of the aircraft. Incidentally, the more important operating concerns have printed schedules, a copy being used for each overhaul, and every item has to be signed for by the ground engineer who passed the particular item of work.

In addition to the schedules a rough notebook should be maintained in which particulars of all work done on an engine or adjustments made to the installation should be entered. These notes are not only necessary for the subsequent completion of log book entries, but since there is not the same need for brevity they can be elaborated and include minor observations of value for reference at a subsequent examination. A periodic review of such notes will often suggest additional items for inclusion in the schedules.

It is false economy to attempt to fit circlips, split pins, and similar locking devices that have been used previously. These parts become unduly

stressed in the process of assembly and dismantling, and their safety factor if reassembled is reduced considerably.

Therefore, make a practice of destroying these parts as they are dismantled in order to prevent their future use.

It is often found that a costly part has become worn at one or two points only—say on a journal which carries a ball or roller bearing. Such parts if otherwise serviceable can be salved by electrically depositing metal on to the worn surface to bring it up to its original or even to slightly larger dimensions. Only iron or nickel should be used for this purpose, copper being too soft. This work may only be entrusted to firms whose process has been approved by the Air Ministry.

The process can be applied to almost any part where the skin friction loading is not too high. It should not, however, be used for making good wear on splines of highly stressed shafts and similar parts, since there is a danger from the deposit obscuring some defect developing in the base metal.

When entering particulars in the engine log book of any replacements made it is a good plan to quote the Release Note No. under which the part(s) fitted were received.

This is outside the official requirements, but the record may be of value at some future date should any trouble arise with the part(s) in question. It also tends to condense records.

PART II

THE LAW RELATING TO CIVIL AVIATION

By A. McISAAC

INTRODUCTORY—National Control of Flying—International Control of Flying—Control of Flying in Great Britain—Conditions of Flying—Compulsory Instruments and Equipment—Personnel and Log Books to be Carried—Rules for Air Traffic—Lights and Signals—Customs—Pilots' Licences—Navigators' Licences—Ground Engineers' Licences—Conclusion

Introductory

CIVIL aviation as a factor in the practical everyday life of any community can be said to have been non-existent prior to the Great War, 1914–1918. Any flying which took place before then—the first flight made by Wright, the crossing of the Channel by Blériot, and other flights in the various competitions and demonstrations that were held—can be looked upon as being of the nature of experimental or sports flying.

Immediately following the Great War there was a rapid and intensive development of the use of civil aircraft for the purpose of the public carriage of passengers and goods. From this point of view it may be admissible to look upon the year 1919 as that in which civil aviation as a practical means of transport actually had its birth.

It will be evident that this rapid development very soon rendered urgent the question of control of aviation. Such control can be exercised most effectively by the authorities responsible for the public business of any given community and in this country control is effected by means of Orders and Directions which are based on an Act of Parliament known as the Air Navigation Act.

In the following pages is given an outline of the main points in the law relating to civil aviation that will help the reader to a clearer understanding of those things with which he ought already to be acquainted. No attempt will be made to cover the whole field and it cannot be hoped that the study of the information given here could ever be accepted as a substitute for a study of the various Orders and Directions themselves. A full understanding of the matters involved can only be gained by the detailed study of the official pronouncements. It is useful to think of the very large body of motorists who serenely carry on without any accurate knowledge of the law relating to road traffic. The average motorist's knowledge of that law is confined to those little bits of information he acquires from reading press accounts of prosecutions under the Road Traffic Act, or, in some cases, by means of the more unpleasant way when he himself has been prosecuted and perhaps penalized. Despite the possible serious consequences arising from his ignorance, the motorist does not seem to think it worth while to make a personal study of the Road Traffic Act.

It may be that aviators as a body differ in this respect and do in fact know the provisions of the various air regulations, but in case this should not be so, the attempt is being made here to outline the main requirements that are peculiar to aviation. It should be borne in mind, however, that

aviators, like everyone else, are subject to numerous laws, the understanding of all of which would make one the complete lawyer. No attempt, therefore, will be made to deal with common law, insurance law, customs law, or any other of the various special laws that may be involved in aviation. Ignorance of the law cannot be pleaded as a defence in any proceedings, and it is the purpose of the following pages as far as possible to reduce ignorance of the law relating particularly to civil aviation.

National Control of Flying

Control of civil aviation in Great Britain and Northern Ireland has been effected through various Acts of Parliament, several of which were placed on the Statute Book between the years 1911 and 1919. As a result of the large development of civil aviation and other causes following the Great War, a new Act was passed including all the previous provisions, which Act is known as the Air Navigation Act, 1920.

Under the provisions of this Act, Statutory Rules and Orders are issued from time to time by His Majesty's Privy Council. The first of such Orders was the Air Navigation Order, 1922. This was superseded and cancelled by the Air Navigation (Consolidation) Order, 1923. Both the Air Navigation Act of 1920 and the Air Navigation (Consolidation) Order, 1923, are still in force.

Detailed administration of the Act is effected by means of the Air Navigation Directions, which are issued from time to time by the Secretary of State for Air.

Control is similarly effected in British Colonies and Protectorates by means of the Air Navigation (Colonies, Protectorates, and Mandated Territories) Order which differs from the Air Navigation (Consolidation) Order only in such respects as are required for the various local conditions. In turn, the Governments of the various Colonies issue Air Navigation Directions covering the detailed requirements of the Order.

Unlike the Colonies, the Dominions, with their own legislatures, have their own Acts, Orders, and Directions, which are independent of their British counterparts and only related thereto indirectly.

This consideration of national control leads naturally to the question of international control, which is dealt with in the following paragraphs.

International Control of Flying

International control of such things as shipping and communication (postal, telegraphic, wireless) is effected by means of various Conventions which have been the subject of discussion, negotiation, and agreement between the countries concerned. In the same way, aviation is controlled internationally by a Convention ratified by many countries. This Air Convention, dated in Paris the 13th October, 1919, was formulated and signed by plenipotentiaries of the signatory States. It came into force on the 11th July, 1922. The Convention has been ratified by most of the principal nations of the world, notable exceptions being Germany, Russia, Spain, and the United States of America.

The administration of this Convention is vested in a permanent Commission known as the Commission Internationale de Navigation Aérienne (C.I.N.A.) or, in this country, as the International Commission for Air Navigation (I.C.A.N.). This Commission, composed of representatives appointed by the contracting States, is placed under the direction of the

League of Nations and is charged with the duties of modifying or amending the provisions of the Convention or its technical Annexes, the dissemination to the contracting States of information of every kind concerning international air navigation, and so on. Modification of the Convention or of its various technical Annexes is effected by means of Protocols, which likewise are subject to the ratification of the various countries subscribing to the Convention.

The subjects dealt with by this Convention are numerous and important. They include airworthiness, certification and registration, marking, personnel, equipment, customs, navigation, lights and signals, meteorology, traffic rules, and other matters connected with aviation which may have an international bearing.

Flying between any two States which are parties to the Convention is more or less straightforward and is governed by the requirements of the Convention itself. On the other hand, flying to or from a country which is not a contracting State may lead to difficulties and the aviator should make himself conversant with any other agreements or rules that may be in existence. Many agreements of such a bilateral nature exist; for example, that between Italy and Spain, and that between the United States of America and Canada.

It will be evident to the reader that international regulation is necessary if international flying is to be undertaken, but it may not be so evident that international requirements must reflect to a large extent the main points in the regulations of the various States. Quite naturally the international reacts back on the national, so that the tendency is towards a standardization of these requirements.

The Convention therefore sets out rules that are more or less in line with those existing in this country. Thus it is seen that aircraft must be registered and in possession of a valid certificate of airworthiness, the personnel (pilots, navigators, and engineers) must be licensed, prescribed log books must be carried, equipment as laid down must be fitted, and the aircraft must be operated in conformity with specific traffic rules and rules as to lights and signals.

The minimum requirements relating to the strength of aircraft have not yet been agreed upon internationally, and until such has been done these minimum requirements are determined by each of the contracting States according to its own ideas in the matter.

The qualifications required by licensed personnel is a matter on which agreement has been reached. We thus find in the Convention that pilots of private flying machines have to produce evidence of competency by undergoing practical flying tests whilst pilots of public transport machines have to undergo much more severe practical flying tests (including night flying) and to pass a technical examination on machines, engines, traffic rules, and elementary meteorology.

In the fields of meteorology, ground markings and lights and signals, we meet with those points on which international agreement is a *sine qua non*. Meteorology, for example, either from the point of view of its development as a science or that of its practical utilization for flying, is dependent on international co-operation. It is in these branches of the art of flying that the Convention lays down rules codified to the greatest extent.

A detailed examination of some of the requirements operating in Great Britain will be made later, and, as these to a very large extent are similar to the international requirements, no more need be said here regarding the Convention.

Control of Flying in Great Britain

The aviator in Great Britain is essentially bound by the Air Navigation Act, 1930, the Air Navigation (Consolidation) Order, 1923,[1] and the Air Navigation Directions,[2] all as amended to date. The Air Navigation (Consolidation) Order will repay careful study from the point of view of the general conditions of flying and the Air Navigation Directions from the point of view of the technical requirements relating to machines and personnel.

In addition to these Orders and Directions, the Air Ministry frequently publishes Notices to Airmen which are of an explanatory or warning character.

It cannot be too strongly urged that all aviators should acquire a knowledge of the Orders and Directions. Without this knowledge infringements may be committed which may lead to serious penalties or consequences. It will suffice here to point out that any infringement of the regulations could lead to the imposition of a fine of £200 or to six months' imprisonment, or both. In addition to these penalties, circumstances may arise where licences may be suspended or cancelled, and, further, an aircraft may even be fired on if it is flown over a prohibited area.

Conditions of Flying

Perhaps the main requirements that must be met before a machine may fly are that—

A.N. Order, Art. 3

(*a*) The machine must have a Certificate of Airworthiness and a Certificate of Registration; the pilot must be licensed; or

(*b*) In the absence of the aforementioned certificates, the machine must have a permit to fly, in writing, from the Secretary of State for Air; or

A.N.D. 11, Para. 60

(*c*) The machine must be flown under special conditions outlined in the Air Navigation Directions known as the "A" or "B" conditions.

The first two cases mentioned above are self-explanatory. The case at (*c*), however, requires some explanation. Formerly it was permissible for unlicensed or unregistered aircraft to be flown provided that the flight took place within three miles radius of a recognised aerodrome. This very elastic condition was open to serious abuse and is no longer in force. The "A" or "B" conditions are designed to allow the same or even greater latitude under proper safeguards. Briefly stated, the "A" conditions permit the flying of an aircraft without a certificate of airworthiness provided that the flight is a *bona fide* test flight under authorised supervision for the purpose of the issue or renewal of a certificate of airworthiness; the "B" conditions relate to experimental flying in such a way that certain people, including most of the established aeroplane constructors, are authorised to fly anywhere in the country machines which are neither registered nor certified as airworthy, the only requirement being that the machines, if not already registered and bearing the normal registration marks, bear a distinguishing mark which is allotted to each such authorised person to show that the machines are being flown under these conditions.

A.N. Order, Schedule I

The Certificate of Registration for any aircraft (fee, £1 1s.) lasts indefinitely and depends only on the continuation of ownership of the machine by one individual.

[1] The Air Navigation (Consolidation) Order, 1923, published by H.M.S.O. at 1s. 3d.
[2] The Air Navigation Directions, 1932 (A.N.D. 11), published by H.M.S.O. at 9d.

The Certificate of Airworthiness lasts for one year and is renewable, the fee for initial issue (in the case of "subsequent" aircraft) and for renewal being £5 5s. on each occasion.

A.N. Order, Schedule II

The issue of a certificate of airworthiness for a new type of aircraft depends on official approval of design, official inspection of construction and official flying trials.

A.N.D. 11, Para. 36

It is to be noted here that the modification of an existing aircraft likewise requires official approval of design and official inspection, but official flying trials are not always required in such cases. The fees payable for a "type" certificate of airworthiness vary with the tare weight of the machine and are specified in the Air Navigation Order.

A.N. Order, Schedule II, Para. 2

The issue of a certificate of airworthiness for a subsequent aircraft (i.e. a replica of a type already approved) follows a recommendation made by approved constructors or, where the constructor is not approved for the purpose of such recommendations, by the Aeronautical Inspection Directorate, Air Ministry.

A.N.D. 11, Paras. 37 & 38

Aircraft are always certified as airworthy (i.e. a certificate of airworthiness is issued) in one or more of three categories: "Normal," "Acrobatic," "Special"; and in one or more of a number of subdivisions as: "Subdivision (*a*), Public Transport for Passengers," "Subdivision (*d*), Private," "Subdivision (*f*), Racing or Record." It is the responsibility of the pilot to see that the machine is not used for any purpose for which it is not certified.

A.N. Order, Schedule II, Para. 3

Renewal of the certificate of airworthiness is dependent on the inspection and recommendation of an authorised inspector. "Hire and Reward" machines (i.e. machines engaged regularly in what is best described for this purpose as fare-paying passenger carrying) are inspected and recommended for renewal by the Aeronautical Inspection Directorate. All other machines are inspected and recommended for renewal by the Joint Aviation Advisory Committee, which is an organisation composed of two older bodies, Lloyd's Register and the British Corporation Register of Shipping and Aircraft. The Joint Aviation Advisory Committee has been specially approved by the Air Ministry for such activities. It will be noted from the foregoing that a subsequent machine may be built, certified as airworthy and its certificate of airworthiness renewed without any official intervention.

There are other general conditions of flying, amongst which may be mentioned the following—

A.N. Order, Art. 4

A flying machine may not land in nor fly over any prohibited area at a lower altitude than 6,000 ft. The prohibited areas are defined in the Order.

A.N. Order, Art. 15

Every flying machine must carry the prescribed documents. In all cases these include the certificates of airworthiness and registration and a journey log book kept up to date.

A.N. Order, Art. 13

Dropping of articles from aircraft in flight is strictly prohibited except in the case of ballast allowed by the Order, i.e. fine sand or water, or as permitted in writing by the Secretary of State.

A.N. Order Art. 9

An aircraft may not be flown over any city or town except at such an altitude as will enable it to land outside the city or town without means of propulsion.

An aircraft must not be used to carry out any trick flying or exhibition flying over any populous area or over any concourse of people, such as a regatta or a race meeting, without the written permission of the promoters, nor may it be flown at such a low altitude as to cause unnecessary danger to persons or property.

A.N. (Amendment) Order, 1933

An aircraft may not be used for wing-walking or any other such exhibition purpose for which the structure has not been designed, unless permission in writing for such purpose has been obtained from the Secretary of State.

A.N. Order, Art. 14

Every aircraft must carry the prescribed instruments which must be maintained in working order.

A.N. Order, Art. 18

An aircraft engaged on international flying must not be used for the carriage of explosives, arms, or munitions of war.

A.N. Order, Art. 22 and Schedule VIII

Every aircraft flying to or from this country must land at or take off from a Customs aerodrome and must pass between such points as may be prescribed.

The foregoing conditions are applicable in all cases, but in addition to these there are certain further conditions applicable to hire and reward machines. These include the following—

A.N. Order, Schedule II

Any aircraft plying for hire and reward is not permitted to fly unless it has within twenty-four hours been inspected and certified as safe for flying. This inspection and certification must be made by licensed ground engineers. The certificate, which lasts for twenty-four hours, is made out in duplicate, one copy being carried in the journey log book and one copy retained by the owner for six months.

The pilot of any such hire and reward machine must satisfy himself that the aircraft is satisfactorily loaded for safety in flight.

For the purpose of so satisfying the pilot in the case of any flying machine which may be employed on a regular line or service of public air transport, a load sheet containing the prescribed particulars must be completed and submitted to the person in charge of the aircraft. This load sheet must be kept by the owner of the aircraft for six months.

Compulsory Instruments and Equipment

A.N. Order, Schedule II, Para. 9

The pilot of an aircraft is responsible for seeing that it is furnished with the prescribed instruments and equipment. What these must be depends on the classification of the machine and the purpose of the given flight. The main points to be remembered in this connection are set out in tabular form opposite. It will be seen that certain equipment is essential in all machines during all flights and that the additional compulsory equipment can readily be ascertained for flights in the special circumstances enumerated.

Personnel to be Carried

In addition to any other specified members of the crew, every flying machine used for the international carriage of passengers or goods for hire

or reward must carry a navigator with first or second class licence if flying—

A.N.D. 11, Para. 78 more than 100 miles over inhabited regions or more than 100 but not more than 625 miles over the high seas or uninhabited regions or, by night, more than 16 miles but not more than 625 miles.

In the same circumstances a navigator with a first class licence must be carried if the machine is flying—

A.N.D. 11, Para. 79 more than 625 miles over the high seas or uninhabited regions or, by night, more than 625 miles.

In certain circumstances the pilot who holds the necessary navigator's licence may, even if he is alone on board, fulfil the duties of navigator in the former case.

	Classification of Aircraft	Nature of Flight	Compulsory Instruments and Equipment
A.N.D. 11, Para. 23	All flying machines	All flights	Air speed indicator Altimeter Revolution indicator, and Such gauges as are considered essential (usually approved as a part of the type design of the aircraft) Safety belt for each person in an open cockpit and for the pilot(s) whether in open cockpits or not
A.N.D. 11, Para. 63	All flying machines	Flight by night	Navigation lights Illumination for instruments and equipment
	Amphibian flying machines	All flights	Indicator of position of landing wheels
	Hire and reward flying machines	All flights	Fire extinguisher (if 10 or more seats are fitted, one for each main compartment, with a minimum of two extinguishers) Wireless apparatus (if 10 or more seats are fitted)
	Hire and reward flying machines	Flights extending beyond 20 miles from point of departure	Compass Watch Turn indicator (if more than 5 seats are fitted)
	Hire and reward flying machines	Flights at any point of which the machine is more than 10 miles from land	Lifebelt for each person on board
	Hire and reward flying machines	Flight by night	Landing lights (lamps or wing-tip flares)

Log Books

Every aircraft must carry a journey log book. In addition every aircraft engaged in hire and reward flying must be provided with an aircraft

A.N.D. 11, Sect. X

log book and an engine log book for each engine. Where aircraft and engine log books are not compulsory, a suitable book is to be kept in which repairs, replacements, and like matters may be recorded.

Rules for Air Traffic

A.N. Order, Schedule IV, Para. 21

Flying machines (i.e. power-driven heavier-than-air craft) must always give way to airships and to balloons whether fixed or free.

The rules regarding risk of collision between power-driven aircraft may be summarised as follows—

A.N. Order, Schedule IV, Paras. 26 *et seq.*

When two aircraft are meeting end on, or nearly end on, each must alter its course to the right.

When two aircraft are on courses which cross, the aircraft which has the other on its own right side must keep out of the way of the other.

An aircraft overtaking another must keep out of the way by altering its own course to the right and must not pass by diving.

Every aircraft following an air traffic route, which has been officially recognised, must keep such route at least 300 yards on its left.

These may be said to be the main points to be observed whilst in flight and away from the aerodrome. There are many other points involved whilst the machine is at, leaving, or approaching the aerodrome. As these do not lend themselves to simplified description and as any failure in their observance might involve litigation or other heavy expenses in connection with third party damages or insurance, the interested reader is advised to refer directly to the appropriate section in the Air Navigation Order.

Lights and Signals

Navigation lights are compulsory for all aircraft flying by night. The lights to be shown are as follows—

A.N. Order, Schedule IV, Sect. 1 (A)

On the right side: a green light,
On the left side: a red light,
At the rear: a white light,

all of which lights are to be visible over a prescribed distance and in prescribed angles.

If the maximum span of a flying machine is less than 65 ft., one lamp placed centrally and combining these three requirements may be used.

In addition to the lights mentioned above, every flying machine which is under way on the surface of the water, under control and not being towed, is required to display a white light to show forward and be visible at a prescribed distance and in a prescribed angle.

A.N. Order, Schedule IV, Sect. II

An aircraft wishing to land at night on an aerodrome having ground control must make intermittent signals either with a lamp or projector other than the navigation lights, or with any sound apparatus. In addition it must signal in Morse code by the same means the two-letter group composed of the first and last letters of its five-letter registration mark. Permission to land will be given by the same two-letter sign from the ground in green light, followed by intermittent signals of the same colour.

The firing of a red light or the display of a red flare from the ground is to be taken as an instruction that the aircraft is not to land.

An aircraft compelled to land at night must, before landing, make with its navigation lights a series of short and intermittent flashes.

Customs

Any aircraft going abroad or coming from abroad must leave or land at a Customs aerodrome, and, in addition, must cross the frontiers between specified points. Where circumstances beyond the control of the pilot force it to cross frontiers elsewhere, the machine must be landed at the nearest Customs aerodrome, and if it is forced to land before reaching such an aerodrome, the pilot is required to report the matter immediately to the nearest police or Customs authorities. In either case the machine may leave again only with the permission of these authorities.

A.N. Order, Schedules VIII and IX

In every case of export, the consignors are required to make a detailed Declaration of the goods in question, and, in addition, a Manifest or general declaration of cargo is to be provided for each such journey of every aircraft. Both these forms are prescribed by the Commissioners of Customs and Excise.

Clearance by the Customs authorities is required before the aircraft may leave a Customs aerodrome and for this purpose the pilot has to produce to the Customs officer—

(*a*) The Journey Log Book,

(*b*) The Manifest and Declaration mentioned above, and

(*c*) An application for clearance on a prescribed form in which is to be stated the Customs aerodrome or aerodromes at which it is intended to land.

These documents, when signed and stamped by the Customs Officer, constitute the clearance.

On landing at any Customs aerodrome from abroad, the pilot is required to make a report to the Customs Officer, produce the journey log book, manifest and declaration of cargo properly cleared at departure, and to land all passengers for examination of baggage. Unloading of goods may not be commenced until this report has been made and the authority of the Customs Officer obtained.

Pilots' Licences

Licences for pilots of flying machines are of two kinds —the "A" licence, which is required by a pilot of a private machine, and the "B" licence, which is necessary before a pilot may fly a machine for hire and reward.

A.N.D. 11, Paras. 82 *et seq.*

Licences may be obtained at any time, there being no fixed periods or places at which tests or examinations are to be undertaken.

"A" licences remain valid for twelve months and are renewable. The fee payable is 5s., but a further £1 1s. is payable if an official medical examination is needed and another £1 1s. if an official flying test is required. Proofs of competency, medical fitness, and recent flying experience are called for. These requirements are usually met by submitting a certificate as to competency, obtained from the Royal Aero Club, and a certificate as to medical fitness made out on C.A. Form 61 by a duly qualified medical practitioner. Three hours solo flying experience during the preceding twelve months is required before such a licence is issued or renewed.

"B" licences remain valid in the case of males for six months and in the case of females for four months, and are renewable. The fees payable are 5s. for the licence, 5s. for a technical examination, £3 3s. for an official medical examination (10s. 6d. if the medical examination is for renewal), and £10 for an official flying test (if required).

Proofs of competency, medical fitness, and recent flying experience are called for. With regard to competency, the applicant must be possessed

of an "A" licence or undergo the tests required in that case, and, further, undergo the following tests—

A left-hand and right-hand spin.

Two cross-country or oversea flights of at least 200 miles each, during one of which a height of at least 6,500 ft. above the point of departure must be maintained for at least one hour, and including two landings (at points fixed beforehand by the examiners) and terminating with a landing at the point of departure.

A night flight of at least 30 minutes made between two hours after sunset and two hours before sunrise at a height of at least 1,500 ft. above the ground.

A cross-country or oversea flight of at least 200 miles with an examiner on board, and including three forced landings at points selected by the examiner.

General flying for about half-an-hour with an examiner on board and including five landings.

For the two latter tests the flying machine is provided by the Secretary of State.

The technical examination is designed to elicit that the candidate has a satisfactory knowledge of the general construction, functioning and assembly of the aircraft and aero-engines concerned, of his knowledge of rules as to lights and signals, general and special rules for air traffic, and elementary meteorology.

With regard to medical fitness, special examinations are conducted by specially appointed medical officers under the authority of the Secretary of State, and it is to be noted that this medical examination must be undergone before a licence is renewed, after illness or accident, or when a licence holder has performed a total of 125 hours flying as a pilot within any period of 30 consecutive days.

Flying experience amounting to 100 hours as pilot in sole charge of a flying machine, including at least 30 landings, during the preceding two years is required before such a licence is issued. For renewal it is necessary to produce proof of reasonable flying experience during the preceding six months.

Navigators' Licences

Navigators' licences are of two kinds, known as first class and second class. The applicant for a second class licence is required to be competent in the theory and practice of the calculation of course and distance, the reading of maps and charts, compasses, flight by dead reckoning, navigation by radiogoniometry, international air legislation, signalling, and meteorology. In addition he is required to have had at least two years' air experience during which he must have spent at least 300 hours as an operative member of the crew of an aircraft in flight.

A.N.D. 11, Para. 108

The applicant for a first class licence is required to have a more advanced knowledge of the subjects already indicated, and also of tides and astronomical navigation. In addition, he must have had four years air experience during which he must have spent at least 600 hours as an operative member of the crew of an aircraft in flight, including 100 hours navigating in the air and not less than 15 hours night flying.

A.N.D. 11, Paras. 88 & 92

In both cases a medical examination, to the same extent and under the same conditions as apply to class "B" pilots' licences, is required to be undergone before the issue or renewal of a navigator's licence.

These licences remain valid, in the case of males, six months, in the case of females, four months, and are renewable. The fees payable are 5s. for the licence, £3 3s. for an official medical examination (10s. 6d. if the medical examination is for renewal), and, for technical examination, £5 5s. in the case of first class and £2 2s. in the case of second class licences.

The technical examinations in question take place in London usually about March and October each year.

Ground Engineers' Licences

Licences are issued to competent persons for the purpose of inspecting and certifying aircraft and aero-engines as safe for flight, and inspecting and certifying any repairs or replacements that may be made. These are known as ground engineers' licences and are classified in five categories—

A.N. Order, Schedule II, Para. 11

A. Inspection of aircraft before flight.
B. Inspection of aircraft after overhaul.
C. Inspection of aero-engines before flight.
D. Inspection of aero-engines after overhaul.
X. Other duties required to be performed under the Order (usually specialist duties, such as instrument repair and calibration, magneto overhaul and test, parachute packing, and so on).

Applicants for these licences are required to be not less than 21 years of age, to have had satisfactory practical experience in the duties for which the particular licence is required, and to pass an examination.

These licences remain valid for one year, can be extended, and are renewable. Where the ground engineer is constantly operative renewed licences can be made valid for two years.

A.N. Order, Schedule IV

The fees payable are—

	£	s.	d.
(a) For the issue of a licence—			
In one category	1	1	–
For each additional category		10	–
(b) For the extension of an existing licence—			
In a different category from that already held	1	1	–
In the same category as that already held			
if by examination		10	–
if without examination		5	–
(c) For the renewal of a licence			
If by examination	1	1	–
If without examination		10	–

The examinations, which are oral, are held in London weekly, in Croydon monthly, and in Manchester, Bristol, and Glasgow at three-monthly intervals.

The qualifications required can be considered under the two headings, experience and knowledge.

The experience that is taken as satisfactory varies with the particular kind of licence required. Thus, for example, experience over a greater length of time may be required in the case of an "A" licence than in that of an "X" licence for parachute packing, whilst a still longer period might be required in the case of an "X" licence for instrument repair and calibration. For the main licences in respect of aircraft or engines, it can be taken that a minimum period of two years' practical experience will be necessary.

The knowledge required is likewise related to the particular kind of licence in question. Thus an applicant for an "A" licence is examined on the rigging and maintenance of aircraft and flying instruments; the applicant for a "C" licence on the daily maintenance and top overhaul of

aero-engines and all instruments and equipment related thereto in the aircraft; the applicant for a "B" or "D" licence is examined on the construction of the complete aircraft or engine respectively from raw material to finished product, including workshop processes, heat treatments, and, in the case of the "D" category, engine testing.

A syllabus of the examination is issued to each applicant showing the subjects dealt with in each separate category, and it will be seen therein that for all categories a knowledge of the Air Navigation Order and Directions is required. This is important from the point of view of the duties and responsibilities to be undertaken by ground engineers. An "A" licence authorizes its holder to certify as safe for flight the aircraft named in his licence and to replace parts or components which have already been approved and require assembly only, but it does not permit him to certify any repair work involving workshop processes on the same machine; whilst a "B" licence holder, though authorized to certify such repair work, or even the complete construction of the machine, is not permitted to certify it as safe for flight. In the same sense, a "D" licence holder can certify the complete overhaul and testing of an aero-engine but no one who is not the holder of a "C" licence can certify that the engine is properly installed and functioning correctly in an aircraft and is safe for flight.

Ground engineers must never issue certificates unless their licences clearly cover the matériel in question. Thus a person who holds an "A" licence valid for an aircraft but excluding compass, turn indicator, and electrical services, should not "sign out" a machine in respect of any flight for which these are compulsory.

Being in a position of trust, the ground engineer is frequently appealed to by owners for guidance as to the regulations. In any case, he himself must know the steps that must be taken to ensure the embodiment of compulsory modifications and the use of nothing but approved materials, the equipment and instruments that must be fitted in varying conditions of flight, the kinds of log books that must be carried, the kinds of certificates that must be issued by him, and other matters that are all additional to his "trade" knowledge. It is, therefore, clear that a knowledge of the Order and Directions is imperative in so far as they are concerned with ground engineering, inspection and conditions of flight.

Conclusion

These then are the main points in the law relating to civil aviation. It is not, however, to be taken that these constitute a complete statement in the matter, but it is felt that the grouping, arranging and wording adopted here are altogether suitable as an explanation or as a reminder to the reader.

There are other points which have not been dealt with because the circumstances in which they arise are infrequent. For example, the use of wireless on aircraft and the compulsory equipment that is required for making the prescribed signals when night flying or when inadvertently flying over a prohibited area. The use of wireless apparatus on aircraft is highly specialized, and is, in fact, a complete subject in itself, whilst the signalling equipment mentioned varies with the circumstances of the case.

This statement on the law relating to civil aviation might have been concluded with a list of "Don'ts" addressed to pilots, ground engineers, or operators generally. Perhaps, however, this is best left to the reader and he or she, whether engaged as pilot or ground engineer, is strongly urged to study the sections herein dealing with the activities in which he or she may be engaged and to construct such a list of "Don'ts" for himself.

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D—(A.4)

AERO-ENGINES

INSPECTION OF
DURING MANUFACTURE, OVERHAUL, AND TEST

("D" LICENCE)

BY
A. N. BARRETT, A.M.I.A.E., A.F.R.Ae.S.

The Air Ministry, whilst accepting no responsibility for the contents of this book, recognizes it as a textbook that should prove to be of value to intending applicants for Ground Engineers' licences

Part
IV

CONTENTS

APPENDICES

ILLUSTRATIONS

PLATES

ELEMENTS AND THEIR SYMBOLS

Element	Symbol	Atomic Weight	Atomic Number	Element	Symbol	Atomic Weight	Atomic Number
Aluminium	Al	27·0	13	Molybdenum	Mo	96·0	42
Antimony	Sb	120·2	51	Neodymium	Nd	144·3	60
Argon	A	39·9	18	Neon	Ne	20·2	10
Arsenic	As	74·96	33	Nickel	Ni	58·68	28
Barium	Ba	137·37	56	Niton	Nt	222·4	86
Bismuth	Bi	209·0	83	Nitrogen	N	14·008	7
Boron	B	10·9	5	Osmium	Os	190·9	76
Bromine	Br	79·92	35	Oxygen	O	16·0	8
Cadmium	Cd	112·40	48	Palladium	Pd	106·7	46
Calcium	Ca	40·07	20	Phosphorus	P	31·04	15
Carbon	C	12·005	6	Platinum	Pt	195·2	78
Cerium	Ce	140·25	58	Potassium	K	39·10	19
Cæsium	Cs	132·81	55	Praseodymium	Pr	140·9	59
Chlorine	Cl	35·46	17	Radium	Ra	226·0	88
Chromium	Cr	52·0	24	Rhodium	Rh	102·9	45
Cobalt	Co	58·97	27	Rubidium	Rb	85·45	37
Columbium	Cb	93·1	41	Ruthenium	Ru	101·7	44
Copper	Cu	63·57	29	Samarium	Sa	150·4	62
Dysprosium	Dy	162·5	66	Scandium	Sc	45·1	21
Erbium	Er	167·7	68	Selenium	Se	79·2	34
Europium	Eu	152·0	63	Silicon	Si	28·1	14
Fluorine	F	19·0	9	Silver	Ag	107·88	47
Gadolinium	Gd	157·3	64	Sodium	Na	23·0	11
Gallium	Ga	70·1	31	Strontium	Sr	87·63	38
Germanium	Ge	72·5	32	Sulphur	S	32·06	16
Glucinium	Gl	9·1	4	Tantalum	Ta	181·5	73
Gold	Au	197·2	79	Tellurium	Te	127·5	52
Helium	He	4·0	2	Terbium	Tb	159·2	65
Holmium	Ho	163·5	67	Thallium	Tl	204·0	81
Hydrogen	H	1·008	1	Thorium	Th	232·15	90
Indium	In	114·8	49	Thulium	Tm	169·9	69
Iodine	I	126·92	53	Tin	Sn	118·7	50
Iridium	Ir	193·1	77	Titanium	Ti	48·1	22
Iron	Fe	55·84	26	Tungsten	W	184·0	74
Krypton	Kr	82·92	36	Uranium	U	238·2	92
Lanthanium	La	139·0	57	Vanadium	V	51·0	23
Lead	Pb	207·2	82	Xenon	Xe	130·2	54
Lithium	Li	6·84	3	Ytterbium	Yb	173·5	70
Litecium	Lu	175·0	71	Yttrium	Yt	89·33	39
Magnesium	Mg	24·32	12	Zinc	Zn	65·37	30
Manganese	Mn	54·93	25	Zirconium	Zr	90·6	40
Mercury	Hg	200·6	80				

[The atomic weight of an element is the weight of an atom of that element as compared with an atom of Hydrogen, which is the lightest known element.]

[The atomic number expresses the position of the element in the periodic table.]

ABBREVIATIONS

Ft.	=	Foot	km.	=	kilometre
Lb.	=	Pound (Av.)	S.G.	=	Specific Gravity
dr.	=	dram	Hg.	=	Mercury
gr.	=	gramme	H_2O	=	Water
kg.	=	Kilogramme	E.M.F.	=	Electro Motive Force
cm.	=	centimetre	π	=	3·1416

INSPECTION OF AERO-ENGINES

Introduction

THE following notes, which deal with the inspection of aero-engines during manufacture, overhaul, and test have been written for those who are studying with a view to qualifying for the Ground Engineers' "D" Licence, and the first step is to procure a copy of the Air Navigation Orders, and the latest issue of the Air Navigation Directions. These are both obtainable from H.M. Stationery Office, Adastral House, Kingsway, W.C.2.

Section 3, paragraphs 44 to 54, of the latter document, give particulars relating to the licensing of Ground Engineers and the regulations and conditions governing the issue of a licence.

Paragraph 47 calls attention to the syllabus of the oral examination, referred to in sub-paragraph (*b*) of the previous paragraph in the section. This syllabus is known as Air Ministry Pamphlet No. 34, and should be obtained at the first opportunity. It stresses the importance of studying the Air Navigation Act and the Air Navigation Directions, and with particular reference to Category D the following sections of the Air Navigation Directions are of the utmost importance.

Section 2 (*c*), paragraphs 19 and 20. Here you will find the inspectional requirements that must be exercised throughout the manufacture, and equally the overhaul or rectification of an engine. In effect, it comprises a systematic following through of the inspection of every detail and assembly of an engine from the raw material to the finished product.

Section 2 (*c*), paragraph 21. This refers to the limitations imposed on a Ground Engineer as regards the acceptance of parts which do not conform strictly to the approved drawings.

Section 2 (*h*), paragraphs 34 to 36, refer to the incorporation of modifications affecting the safety of an engine as a condition of airworthiness.

Section 5, paragraphs 58 and 59. These state that the standard of material and workmanship, when overhauling or repairing engines, shall be that required for new engines. It also prescribes the form of certificate that must be inserted in the engine log book, and signed by the ground engineer, on the completion of his supervision Approved log books have the certificate printed at the bottom of each page.

The subject-matter in each of the above sections is referred to in detail elsewhere in the book.

Experience

We must now consider what practical experience might be deemed reasonable before a candidate presents himself for examination. In

the first place he must make up his mind for what approved type or types of engine he intends to qualify . It is quite unlikely that he would be examined, except for named types, unless his experience was exceptional and of long duration, and for this reason it would be necessary for him to obtain practical experience of the erection, dismantling, and testing of each type of engine for which he ultimately required a licence.

The regulations specify that "he shall have had at least two years' satisfactory practical experience, provided, however, that in lieu of such two years' practical experience, proof may be accepted that the candidate has otherwise acquired adequate knowledge of the construction or maintenance of aero-engines," after which proof of his capacity to carry out the duties of a ground engineer in a satisfactory manner would be ascertained by an oral examination. It is thought that the necessary practical experience could best be obtained by employment in an established firm manufacturing aero-engines, or, on the other hand, a properly equipped operating company maintaining their own engines. Most of the time should be occupied in erecting, stripping, and testing engines, preferably those received for overhaul and repair, because it is unlikely that the ground engineer will eventually operate his licence in the manufacture of new engines. The adequacy of the experience so gained would be carefully considered in relation to the number and type of engines applied for, and it will doubtless be necessary to produce testimonials to support this experience. There would be no objection to the candidate applying for one engine only, and adding others to his licence at later dates after the necessary experience had been obtained. If the candidate wished to include any foreign type of engine on his licence, he would be required to produce evidence that he was familiar with, and had overhauled, the particular engine in question, and the statements might, of course, be subject to verification, but even then it is very doubtful whether engines in this class would be considered unless the candidate already held a licence for other engines.

Experience of the kind already referred to would not, of necessity, fit the candidate for satisfactorily fulfilling the requirements of the oral examination, because it is my experience that a person employed in a factory, even though he is erecting and stripping engines, may not have the opportunity of handling certain of the components and accessories, if they are dealt with in other sections of the works, and it should be realized, therefore, that some of the knowledge of an engine that is required may have to be obtained in ways other than from practical experience. In this connection the candidate is strongly recommended to obtain any information, literature, and handbooks that are available on the particular engine in which he is interested. In those instances where the civil type of engine is also a service engine he is advised to obtain the *Service Handbook* from H.M. Stationery Office. These books are very complete and should be exceedingly helpful.

He should also obtain a personal copy of the *Airworthiness Handbook*, A.P. 1208, and amendments from H.M. Stationery Office. This book indicates the detail requirements of a type aircraft which includes,

of course, the engine, in order that it may qualify for a certificate of airworthiness in accordance with Section 2 of the Air Navigation Directions. What is equally important, the book also contains particulars of the bench tests that must be carried out on civil engines after overhaul or rectification, with all of which it is essential for the candidate to be familiar. It also includes a series of Inspection Leaflets of immense value (see Notice to Aircraft Owners and Ground Engineers, No. 39, of 1936), in that they amplify the requirements of the Air Navigation Directions in regard to manufacturing processes. I shall have occasion to refer to some of these Inspection Leaflets in detail later on. Meanwhile, I will say just a few words about Inspection Leaflet No. 100 (A.P. 1208), which includes a chart showing the complete chain of inspection of an aero-engine, and which satisfactorily meets the requirements of the Air Navigation Directions. The leaflet explains at some length the significance of, and the reasons for, the various inspection stages. It will be noted that a record of inspectional responsibility is maintained throughout, either by release note, inspector's stamp on the part, book record, or log sheet signature. The candidate should carefully consider this leaflet, which is applicable equally to new and repair engines, because the oral examination is largely moulded around the various stages.

Approved Material

It should be clear that a ground engineer, holding a licence in category "C," is only permitted to fit approved spares, that is to say, spares supplied by a constructor whose inspection organization has been approved by the Air Ministry. These firms are permitted to manufacture engines and their spares, inspect them by their own Inspection Departments, and subsequently release them, it being necessary, however, to include on their release notes the required certificate and approval reference issued by the Air Ministry. The holder of a "D" licence is considered to have attained sufficient specialized knowledge to enable him to supervise the manufacture and inspection of approved spares, as well as the overhaul and test of the engine into which the spares are subsequently built. It should be clear, then, that the raw material from which approved spares are to be made must also be obtained from, and properly released by, approved firms.

Ferrous materials would be supplied either in the form of bars, billets, forgings, stampings, sheets, or castings. The accompanying release note and test certificates (the latter showing that the relative specification had been met) would enable the material, which would be stamped and batched, to be correlated at the contractor's works. The release note should also indicate whether the material was in the normalized or heat-treated condition. Inspection Leaflet No. 410 (A.P. 1208) deals with the identification of the above material.

The Air Navigation Directions require the candidate to satisfy the Examining Board that he has a sufficiently good knowledge of materials to enable him properly to check incoming raw material and supervise the manufacture of spare parts. Space does not permit me

to deal with the question of materials beyond the standard that may be expected to meet the requirements of the syllabus, but the candidate would be well advised to extend his knowledge by referring to one of the many textbooks on the subject; in particular, it is thought that a knowledge of the iron carbon equilibrium diagram Fig. 3 would be of assistance in more clearly understanding heat-treatment and case-hardening processes.

Specifications

SPECIFICATIONS OF MATERIALS SUITABLE FOR AERO-ENGINE COMPONENTS

Component	Material	Specifications
Crankshaft	High tensile alloy steel	4.S.11, S65, S.81
Reduction gears	Case-hardening steel	S.82, S.90
Smaller gears	High tensile alloy steel	2.S.28, S.90
Connecting rods	High tensile alloy steel	2.S.28, S.65, 4.S.11, L.40
Wrist pins	Case-hardening and high tensile air-hardening steel	S.90, 2.S.28
Gudgeon pins	Case-hardening and high tensile air-hardening steel	S.90, 2.S.28
Cylinder barrels	Carbon steel	2.S.6, S.70, S.79
Water jackets	Carbon steel sheet	S. 84
Camshaft	Case-hardening steel	2.S.14
Airscrew shaft	High tensile alloy steel	4.S.11
Airscrew hub	High tensile alloy steel	4.S.11, S.65
Airscrew hub bolts	High tensile alloy steel	4.S.11, 2.S.2
Inlet valves	Steel stamping	S.62, D.T.D.49B
Exhaust valves	Steel stamping	D.T.D.6A, D.T.D.49B
Valve springs	Steel (hard-drawn)	D.T.D.5A
Valve seatings	Stampings or bar	S.68, D.T.D.160, D.T.D. 192, 247
Oil pump gears	Bar	4.S.11, D.T.D.194
Push rod ball ends	Case-hardening steel bar	2.S.14
Studs (stressed)	High tensile alloy steel bar	2.S.2, S.69
Piston rings	Cast-iron pots	4.K.6, D.T.D.233, 277
Induction fan	Aluminium alloy	D.T.D.133B
Pistons	Aluminium alloy (cast and forged)	4.L.11, 2.L.24 L.42 D.T.D.131A
Cylinder heads	Aluminium alloy (cast and forged)	4.L.11.D.T.D.131A, D.T.D.133B 3.L.25
Crankcase	Aluminium alloy (cast and forged)	3 L.5 4.L.1, D.T.D.133B
Covers	Aluminium alloy (cast and forged)	3.L.5., D.T.D.133B
Bearing bushes	Phosphor-bronze bar	2.B.8, D.T.D.155
Bolts and nuts (unstressed)	Mild steel bar	3.S.1
Pressings, clips, and brackets	Mild steel sheet	2.S.3, 2.S.4
Tube for piping	20-ton welding steel	2.T.26
Tube for piping	50-ton Ni-Cr steel	T.50
Tube for push-rod covers	Aluminium	4.T.9
Tube for piping	Seamless copper	5.T.7, 2.T.51
Tube for radiators	Brass	3.T.47

Practically all ferrous and non-ferrous materials used in aero-engine construction conform either to the British Standards Institution Specifications for Aircraft Materials and Components, and are obtainable at 28 Victoria Street, London, or in the case of new grades of material that have not yet reached the stage of development that permits standardization, to those known as D.T.D. Specifications, issued by The Director of Technical Development, Air Ministry, and obtainable at H.M. Stationery Office, Kingsway.

The type engine drawings, from which subsequent engines are manufactured, invariably quote the specifications of the various parts on them, and a list indicating suitable material specifications for the principal parts of an engine is included above for information, it being

clear that the ground engineer must become conversant with the actual specifications corresponding to the particular engine he wishes to hold a licence for, and whilst it is quite unnecessary to memorize these specifications, it is necessary to have a working knowledge of them, and to see that each specification bears the latest prefix and suffix according to the requirements of the constructors' specifications.

It is unlikely, other than in the case of an emergency repair, that the manufacture of new parts will become necessary, but in spite of this it is very desirable for the ground engineer to appreciate the characteristics and merits of the various classes of materials that are available for aero-engine construction. There is, for example, a range of case-hardening steels, namely, 2.S.14, 3.S.15, S.82, etc., comprising a straight carbon, a 3 per cent nickel, and a 5 per cent nickel chrome steel respectively. The first of these, if properly heat-treated and case-hardened, will provide the hardest case, whilst the others, owing to the presence of nickel, have stronger and less fibrous cores, and offer greater resistance to shock loading. Case-hardening nickel steels are, therefore, selected for such parts as gear wheels, but the choice of the material by the manufacturer is largely dependent on the duty the part has to perform, and, to some extent, the design. It is also recognized that the addition of nickel and/or chromium to a steel has the effect of slowing down the critical cooling velocity for hardening and permits the use of quenching media other than water.

This property cannot be made use of in the case of straight carbon case-hardening steels.

One advantage, then, of the alloy steel over the carbon steel is that there is much less risk of surface cracks and distortion of parts where oil quenching can be substituted for the more drastic water quench.

A reference to the specifications will show that high-tensile alloy steels such as 4.S.11, S.65, S.69, S.81, etc., are employed in the heat-treated condition for highly-stressed parts, and as a result do not normally permit of any cold working.

It will sometimes be found that similar parts have been manufactured in more than one class of material, and in such cases it may be assumed that normal development by the engine designers has warranted a change in the material to a later or more suitable specification, as the result of some form of trouble which may have shown up in manufacture or during service operation. It may be found that connecting rods, originally made in material to 4.S.11 specification, have been changed to material to 2.S.28 specification. Cylinder heads originally made in material to 4.L.11 specification may subsequently be produced in material to specification L.43, D.T.D.133B, or D.T.D. 131A; the latter is die cast, and aluminium alloys in this condition are known to have a closer grain and improved physical properties. In such cases the drawing will be the guide as to which is the current specification, and in the event of the parts made to an earlier specification being considered unserviceable for use in an engine, such cases would always be brought to the notice of the ground engineer by the promulgation of a Notice to Aircraft Owners and Ground Engineers.

Another class of material which does not permit of any discretion

on the part of the ground engineer is white-metal for bearings. It is safe to say that most proprietary brands of white-metal fall inside the two existing specifications, namely, 2.B.21 and 2.B.22, and it is important that the brand of white-metal specified by the engine makers, and which was tested on the original type engine, must be used in subsequent engines. It is possible that occasion might arise where it becomes necessary to manufacture bushes for wrist pins, gudgeon pins, and other parts of an engine. In these cases it is important that they are made in the material specified on the type drawings. The use of extruded bronze in place of cast phosphor-bronze, might lead to serious trouble. See Plate I. In the same way the use of aluminium bronze in place of magnesium (specification D.T.D.88B) or steel, for pump gears, or *vice versa,* might be undesirable, as the loading on the teeth and clearance might easily have a bearing on the satisfactory functioning of the parts if a change to an unsuitable material were made.

Exhaust valve steels with high-nickel or chromium content normally fall into the austenitic class, and the rates of expansion on heating are often 50 per cent in excess of normal valve steels. In these cases additional valve guide clearance is essential for satisfactory functioning.

If we briefly consider any one of the high-tensile alloy steel specifications used for the more highly-stressed parts in an aero-engine, we shall find that the specification is divided into sections dealing with the various forms of material that can be obtained, and the requirements as regards the selection and preparation of the mechanical test samples are dealt with in each of the various sections.

It will be found that the chemical analysis of the steel is given, and that certain elements may be included at the option of the purchaser. For example, manganese promotes soundness and freedom from gas cavities, and if not present the steel would be liable to "red shortness." The tensile figure is improved and the ductility unimpaired up to 1 per cent of manganese.

The various mechanical tests required, as well as the form of the test bar, are also included. If the material has been heat-treated before delivery to the constructor, as is often the case, a reference to the relative specification may be required in order to be able to check the sub-contractor's release note to see that the various tests, enumerated in the specification, have been complied with. It will be noted that on small bars, where an Izod test piece cannot be prepared, a nicked fracture test may be substituted. The specification also states that where the mechanical tests after heat-treatment do not meet the specification figures a second heat-treatment is permissible. Where heat-treatments have to be carried out at the constructor's works, the various mechanical test bars must be prepared in accordance with the terms of the specification. If facilities are not available for carrying out these tests they would have to be done at an approved test house.

As regards heat-treatments, the temperatures specified are considered to represent an average figure for general practice only for this particular class of material; the exact temperatures would, of course, be supplied by the steel makers and are normally quoted on the covering release note. The specification points out the necessity of identifying

stampings and other parts at all stages throughout the manufacture, and as identification of the major parts has to be carried through to the finished article this point must not be lost sight of.

Cast Iron. This material is only used in aero-engines for piston rings and then contains no more than 3·5 per cent "total" carbon. At elevated temperatures the carbon is taken into solid solution as in the case of steel, but on cooling normally, some carbon is retained in the "combined" form, whilst the rest is precipitated as graphite plates. It is this "free" carbon which makes this class of material excellent as a bearing metal such as would be required for a piston ring moving up and down in a cylinder.

The combined carbon should be not less than ·45 per cent in order that the wearing qualities of the ring are not impaired and to ensure that a fine Pearlitic structure shall be maintained. Combined carbon in excess of ·8 per cent would produce free cementite, which, being very hard, would induce cylinder wear and add to machining difficulties. It is current practice to cast the cylinders or "pots" by a centrifugal process which results in a finer distribution of the graphite and closer grain structure than with the ordinary sand-cast pots, and the risk of inclusions of sand is eliminated. Good quality piston rings can be obtained by casting each ring separately, to dimensions as near as possible to the finished article, but this is probably more costly and the centrifugal method is considered to be an advantage for heat formed rings.

Materials Testing

In order that a specification for material may be fully understood it is necessary for the ground engineer to know the various mechanical tests that are called for, and the reason why they are carried out. It is not essential that he should have actually carried out these tests, and a few details on this particular subject may therefore be helpful.

Tensile Test. This particular test is made in order to determine the ultimate tensile strength, the yield point, the reduction of area, and the elongation of a material. A standard form of test bar is prepared in accordance with the dimensions specified in B.S.I. specification No. 2.A.4. The extremities of the test bar are machined so that they may be accommodated in the jaws of a testing machine. A load is progressively applied to the test bar either by hand, electric, or hydraulic power, according to the type of machine, until it eventually fails in tension.

The test bar is normally machined to ·564 in. diameter on the reduced portion, which corresponds to a cross-sectional area of ·25 sq. in. Two centre pop marks are made on the reduced portion, exactly 2 in. apart. For other sizes of test bar the distance of the gauge points apart is $4\sqrt{\text{area of the test bar}}$, or 3·56 times the diameter of the test bar.

The Yield Point is determined by measuring the extension of these points by means of dividers as the test is in progress, and it will be found that when the yield point is reached there will be a marked extension of the test bar, together with a sudden drop of the beam of

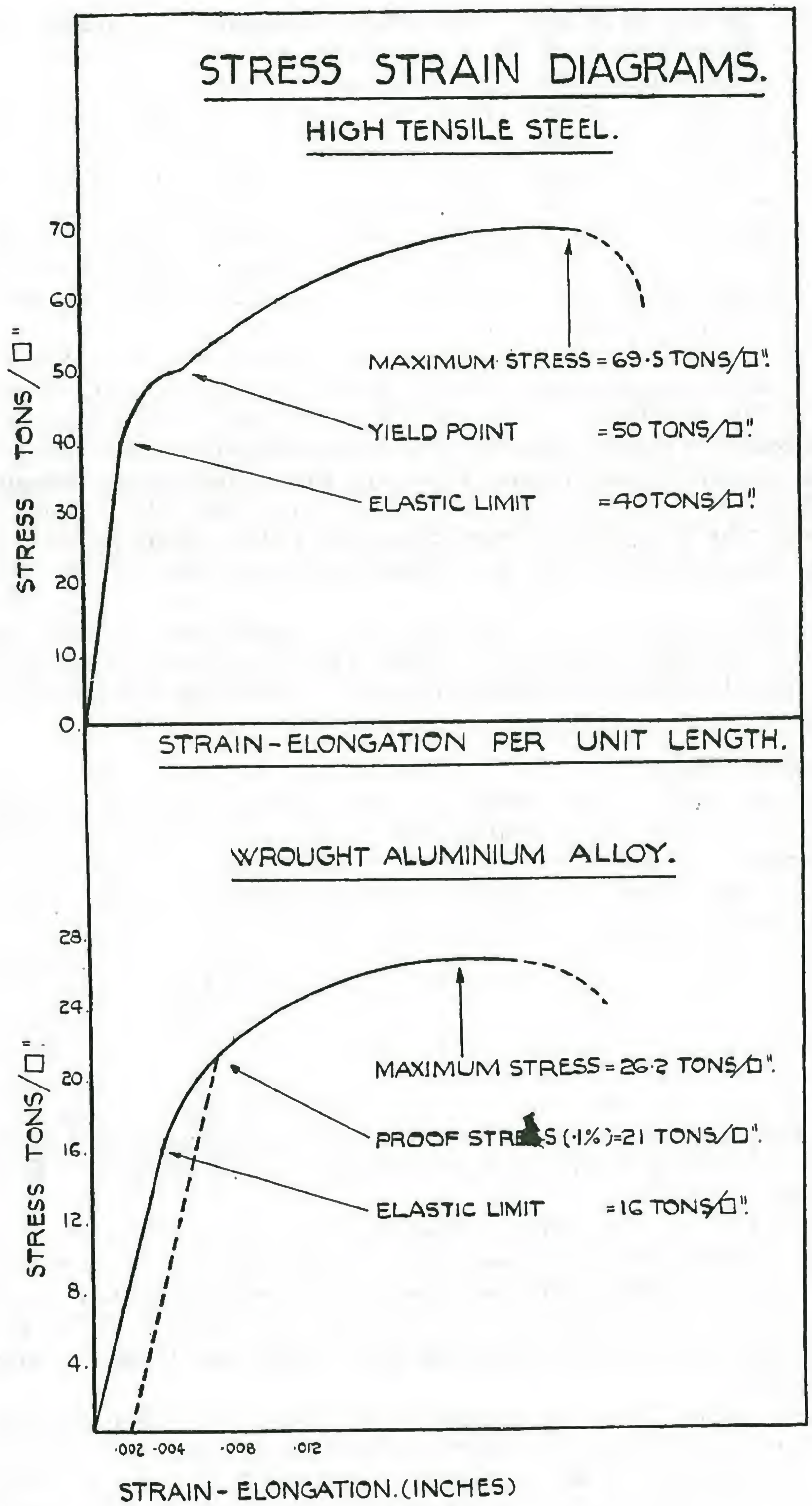

STRESS STRAIN DIAGRAMS.
HIGH TENSILE STEEL.
STRESS TONS/□"
70
60
50
40
30
20
10
0
MAXIMUM STRESS = 69·5 TONS/□".
YIELD POINT = 50 TONS/□".
ELASTIC LIMIT = 40 TONS/□".
STRAIN - ELONGATION PER UNIT LENGTH.
WROUGHT ALUMINIUM ALLOY.
STRESS TONS/□".
28
24
20
16
12
8
4
MAXIMUM STRESS = 26·2 TONS/□".
PROOF STRESS (·1%) = 21 TONS/□".
ELASTIC LIMIT = 16 TONS/□".
·002 ·004 ·008 ·012
STRAIN - ELONGATION. (INCHES)

FIG. 1

Plate I. A Bronze Connecting Rod Bush which Extruded under Working Loads

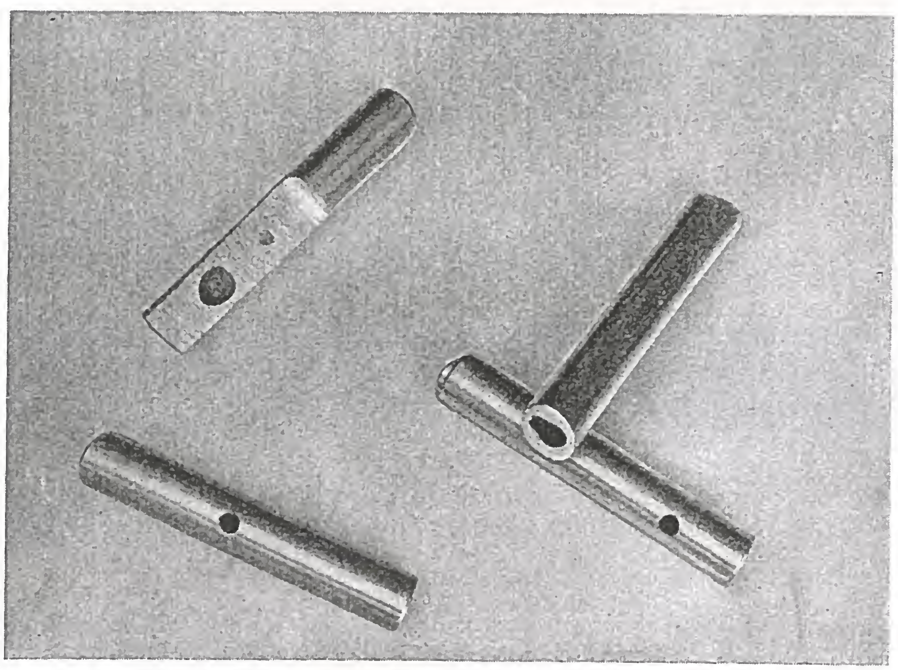
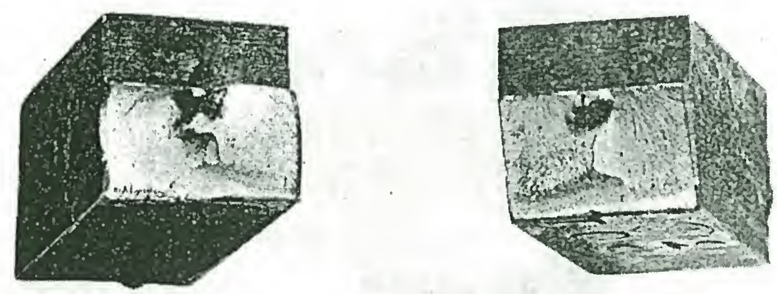
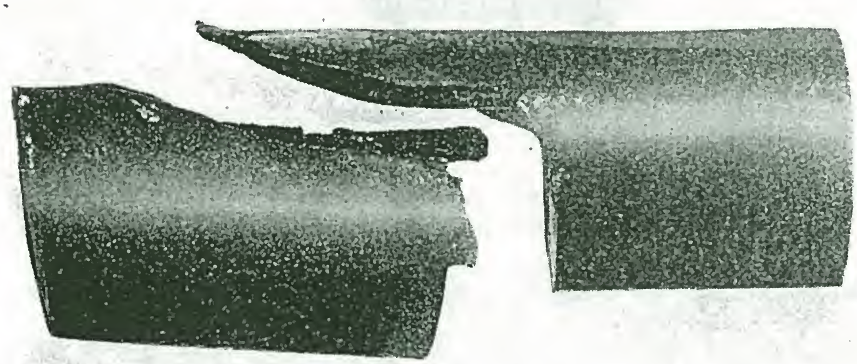


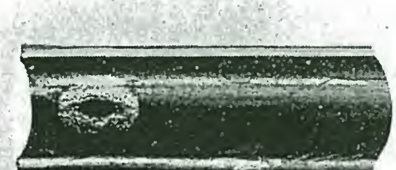
Plate II. $\frac{5}{8}$ in. Diameter Cast Phosphor Bronze Bar showing Blow Holes, Revealed only after Machining



IIIA



IIIB



IIIC

Plate IIIa. Two Fractures of Steel Bar Showing "Pipe"

Plate IIIb. Steel Bar Showing a "Lap," Formed in an Early Stage of Rolling

Plate IIIc. Sectioned Steel Water Pipe Showing Erosion Resulting in a Bad Water Leak

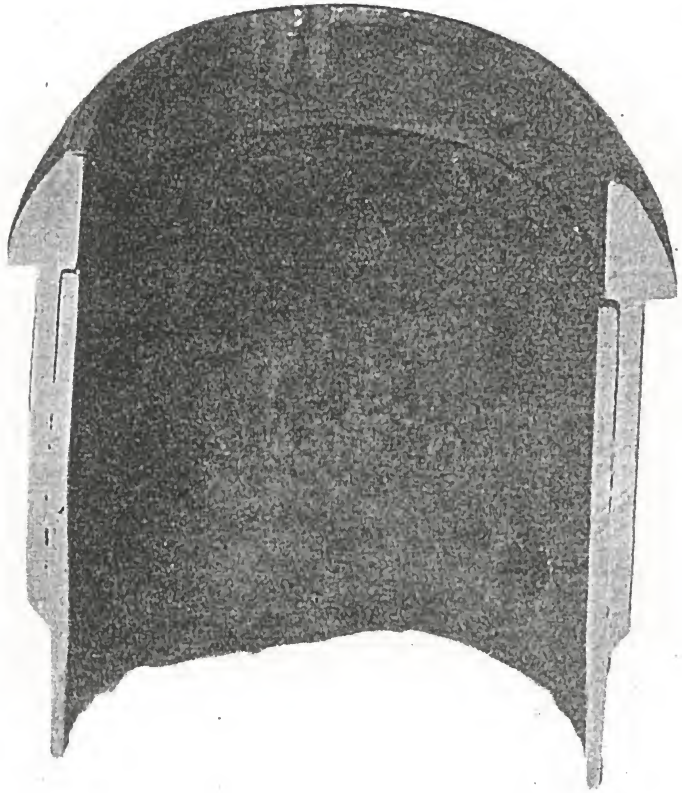


PLATE IVA. OIL PIPE NIPPLE, ILLUSTRATING DEFECTIVE BRAZING

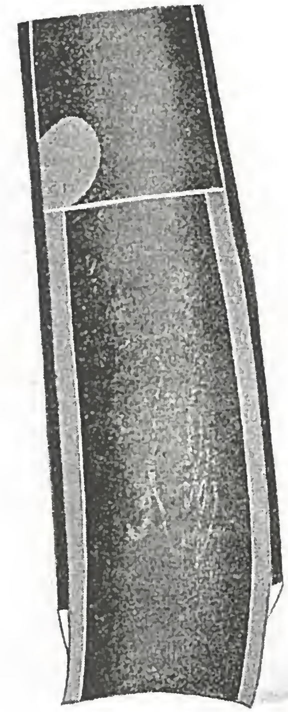


PLATE IVB. A SILVER SOLDERED COPPER TO STEEL PIPE JOINT

Sectioned through a ball of extruded solder which partially blocked the pipe

the testing machine. Whilst this method is sufficiently accurate for routine testing, a more accurate determination would require the use of an extensometer. The yield stress is equal to the load in tons at the yield point divided by the original cross-sectional area of the test bar in square inches. The yield point is sometimes indefinite, particularly on non-ferrous materials, and for this reason certain specifications call for a "proof stress" instead. Proof stress is that point at which the stress strain curve departs, by a specified proportion of the original gauge length, from the straight line of proportionality. This may vary from ·1 to ·5 per cent. Typical stress strain diagrams are illustrated in Fig. 1, and the points referred to above are clearly marked with arrows.

Elongation and Reduction of Area are, to a certain extent, measures of the ductility of the material. The elongation is ascertained, after the test bar has been broken, by placing the two parts together and measuring the distance between the two centre pop marks. The increase in length expressed as a percentage of the original length, namely 2 in., gives the elongation. The reduction of area of the test bar will occur at the point of fracture, due to "necking" that will be noticed. This will be measured and expressed as a percentage of the original area. The ultimate stress is equal to the load in tons required to fracture the test bar divided by its original cross-sectional area in square inches.

Impact Test. This is a test for brittleness, and to determine capacity to resist shock, and suddenly applied loads. It gives a fair indication of the heat-treatment of steel, information which a tensile test does not necessarily show. Steel is composed of numbers of closely united crystal grains the closeness of which cannot be judged by the naked eye. Each grain has well marked cleavage planes along which breakage will occur when a bar is fractured. These cleavage planes show up as bright facets. A crack is either inter-crystalline if it travels round the crystal boundaries, or trans-crystalline if it travels across them as in the case of a fatigue crack. The fracture can be examined to ascertain whether the grain structure is satisfactory. A tough, fibrous structure indicates a correct heat-treatment, whereas a coarse, brittle, crystalline structure is undesirable.

It is important that a good grain distribution is obtained in a forging, and it is estimated that steel is 15 per cent stronger across the fibre than parallel to it. The arrangement of the fibres can only be determined, however, by macro-etching a polished surface.

The Izod machine is used in this country for these tests, and comprises a pendulum swinging in a vertical frame. The test piece is either of square or round section, and is provided with one or more notches, and must conform to the dimensions prescribed by the British Standards Institution. The test piece is held in a vice in such a position that one end is in the path of the pendulum, the notch facing the direction of impact. The test is made by releasing the pendulum from a definite position. The energy absorbed in overcoming the resistance of the test piece to fracture is indicated by the reduction in

swing of the pendulum after the impact, and is measured direct on a graduated quadrant in ft.-lbs.

Brinell Test. This apparatus, being in general use, is probably well known, and no description is, therefore, thought to be necessary. There are other machines, such as the Firth Hardometer, which function in a somewhat similar manner. A 10 mm. diameter steel ball is pressed into the material to be tested, under a load of 3,000 kilograms, and is maintained for a period of not less than 15 sec. The diameter of the impression so formed is then measured with a micrometer microscope. A test of this nature is sometimes sufficient to replace the ultimate stress figures for certain parts, and is useful in re-checking batches of forgings, or bars, which have been heat-treated together with one test bar. It is also valuable in exploring the uniformity of heat-treatment on large forgings and bars. The impression should be made only after the scale has been removed, otherwise errors equivalent to as much as 10 tons per square inch may easily result. The flat on which the impression is made should be smooth and sufficiently wide to prevent bulging, and the impression should be measured across two axes. It is possible to obtain an approximate idea of the ultimate strength of the material measured by multiplying the Brinell number by a conversion factor, as follows: For carbon steels ·23. Alloy steels ·22. High-tensile alloy steels ·21. Take as an example, an alloy steel with a Brinell number of 250. By using the appropriate factor ·22 we obtain an ultimate strength of 55 tons. I will now quote a rule of thumb formula which also gives approximate results. The ultimate stress equals the Brinell number divided by 5 plus 5. Taking the same example we have $\frac{250}{5}$ plus $5 = 55$ tons. It is possible with a Brinell machine to use a smaller ball with a proportional load, for dealing with soft non-ferrous alloys, or finished steel parts, where the larger impression might be injurious. Inspection Leaflet No. 406 (A.P. 1208) describes other hardness testing machines for use where case hardened surfaces have to be checked.

The various testing machines should be periodically checked for accuracy, particularly after one has been transferred to another place. The makers usually supply test blocks with hardness testing machines, in order that comparisons can from time to time be made.

The Izod machine should retain its accuracy provided that all working parts are maintained in perfect order.

Tensile testing machines are best checked by the makers, although there are a number of ways that a check can be effected. The following brief particulars relate to three methods—

(i) Two similar test bars are prepared from the same bar, one is pulled on the machine under check and the other on a machine known to be in good order, and the results compared.

(ii) A test bar is obtained which is known to have a straight stress-strain characteristic up to the yield point. A check within this range can accordingly be effected.

(iii) Known dead loads can be applied and comparisons made on the readings recorded on the beam, when in balance.

Sheet and Tubes. These classes of material are normally delivered in the condition in which they will be used. If sheet has to be bent or made into pressings, or tube has to be bent or welded, some form of stress release thermal treatment may have to be done. In particular cases, heat-treatment after working may have to be carried out and then the relevant Specification must be referred to.

Tubes may be subjected to checks of chemical analysis, flattening and hardness tests, proof stress and tensile tests. For the last two tests the ends of the test piece are either flattened or plugged to provide a suitable grip in the testing machine. Inspection includes an examination for cracks and surface defects, straightness and dimensional accuracy.

Sheets may require checking for chemical composition, and may be subjected to single and reverse bend tests, proof stress and tensile test. For the latter, the test piece is cut so that the load is applied along the direction of the grain. Inspection includes an examination for surface defects, flatness and thickness.

Non-ferrous Material. The quality is controlled in the foundry largely by—

1. The analysis of incoming ingots of virgin metal.
2. Daily analyses of the melts.
3. Tensile tests on test bars representing casts or separate castings

Tensile test bars are cast in standard inclined sand-lined moulds and where they represent individual castings, are wired to them for heat-treatment and ageing. With general castings, that is to say smaller and less important ones, test bars are prepared for each cast up to a definite weight. Three test bars are normally provided, so that if the first one fails to meet the specification figures, a check can be effected. Slight variations in chemical composition may necessitate a change of heat-treatment temperatures.

Material Defects

Passing on to the various defects that must be looked for during the inspection of raw materials prior to, and during, manufacture, it becomes important in the case of hot-worked parts, such as forgings and stampings, to carry out some form of de-scaling, in order that a defect, if present, may be more readily detected. In this connection you are referred to Inspection Leaflet No. 415 (A.P. 1208), which details an approved method for removing scale and rust. Cold-worked material would be pickled. Dealing first with the ferrous materials, such as bars, stampings, and forgings, the defects that are normally encountered include folds, laps, hair cracks, pipe, roaks, slag inclusions, etc., and it may be of assistance if a little information on each of these defects is included at this stage.

Hair Cracks normally show up after a part has been machined, and occur in the direction of working the material. They are due to the elongation of minute blow holes or cavities originally in the structure. Unless the ground engineer has had some considerable experience in dealing with this class of defect it would be his wisest course to reject any doubtful parts. On finished machined parts such as crankshafts,

some discretion by the constructor might be permissible if hair cracks were suspected. It would be wrong to consider the acceptance of a part if hair cracks were intermittent throughout its length, or if cracks appeared in a radius or at a highly stressed position. In certain circumstances it might be permitted to remove a mark by very careful filing, provided the amount of metal removed was not more than several thousandths of an inch deep, and the crack was not more than $\frac{1}{8}$ in. long before it was removed. SLAG inclusion could be dealt with in a similar manner except on nitrided surfaces.

FOLDS AND LAPS usually appear on the outside of a bar or forging, and may be caused by flash edges being rolled or stamped into the material. They can usually be chipped out or removed without detriment to the part. Seams are sometimes caused by hard metallic matter which gets into the lubricant used when drawing small diameter bars through the dies.

ROAKS have the appearance of cracks, and may extend the full length of a bar. They are caused by gas or blow holes, which, having become oxidized, do not weld up again on forging, and are consequently drawn out on subsequent working. They may not be discovered until the parts are finally machined.

"PIPE" is caused by the caving in of the top of an ingot due to the contraction of the metal on cooling, and if present is due to insufficient cropping of the top of the ingot. With aircraft steels the centre of an ingot, where "pipe" might be present, is usually removed, and normally one need not anticipate a lot of trouble from this source. If it is present it may extend down the centre of bars throughout their whole length. In such cases the whole consignment should have a piece knocked off at both ends of each bar as a check.

ALUMINIUM. Foundry technique can be very complicated when producing parts for modern aero engines, as surplus metal has to be eliminated without materially affecting strength or promoting unsoundness: consequently skill and experience only can produce the required standard.

Gravity and pressure die castings are now used for many small parts, but sand castings are more general for the larger ones. Crankcases, however, are produced as castings and also as forgings. A fully equipped foundry has inspectors who check the moulds with very accurate jigs and gauges at each stage, thus safeguarding, as far as possible, uniformity of wall thicknesses, etc., of the finished casting. They also check the temperature of the metal prior to pouring, the furnaces during heat treatment, the pulling of test bars, etc.

Clean scrap, such as risers, headers and unmachined scrap castings are added to virgin metal in agreed quantities.

When fettling castings, care must be taken to remove all sand and core wires. A complicated casting may contain many wires in the moulds which may be difficult to see if they become lodged in passages and corners.

The more general defects met with on castings are laps, contraction cracks, flaws, blow-holes, porosity, short fettling, cold shots, speckiness, thin walls, misplaced cores, and short bosses. Most of these defects can

be readily understood by their names, and a lot can be learned by the periodical sectioning of parts rejected for any of these defects. Pressure tests should be made where possible, to check for porosity, and where doubtful patches appear on the surfaces of parts, prodding with a strong scriber may reveal cavities which would otherwise pass inspection. These cavities have a smooth interior, and are usually formed by steam pockets, the steam from damp moulds being unable to escape from the metal during solidification.

Speckiness in aluminium is a trouble associated with the foundry which always exists to some extent, but if it is very pronounced there is a risk of cracks developing when the part is stressed, due to the linking up of a number of the small holes, and such parts should be rejected. These holes are probably due to the release of dissolved gases present in the raw material. Specky metal is prone to inter-crystalline corrosion whilst magnesium alloys are comparatively free of speckiness.

Contraction cracks may occur due to a marked change in section of the part, and will not, of necessity, develop when subjected to engine running. In certain cases parts might be acceptable if the extremity of the crack was located with a small drilled hole. Contraction cracks may also be caused by the use of heavy chills adjacent to thin sections. Shrinkage allowed by the pattern maker for Al. is approx. $\frac{1}{8}$ in. a foot.

Inclusions may consist of non-metallic oxides, impurities in the raw material, unskimmed dross from the crucible and moulding sand.

Non-ferrous tubes and bars should be examined for die marks, seams and spilleys, the latter being analogous to roaks, associated with steel.

Etching or pickling of light aluminium alloys may dangerously impair the fatigue resistance. Solutions containing caustic potash, caustic soda, washing soda, or acids should normally be avoided.

Protective Processes (see also Section V of Appendix II)

The ground engineer should have a knowledge of the various protective processes as they play an important part in the life of an aero-engine, and attention is particularly drawn to the following.

Chromate Treatment. This is a protective process for magnesium alloy castings against corrosion. The parts are immersed in a bath containing potassium and ammonium di-chromate, ammonium sulphate and ammonia for from 30 to 45 min., the liquid being maintained at boiling point all the time.

The parts are subsequently washed and dried.

This treatment produces a dark brown film, and it is usual to protect this with a coating of cellulose enamel as the film is not very resistant to abrasion. The preliminary cleaning of the parts may be carried out by immersion for half an hour in a 2 per cent boiling solution of caustic soda, followed by a thorough washing in cold water.

The treatment should be applied only after the part is fully machined as otherwise a perfectly good seal against corrosion might be destroyed if machined surfaces, other than faced joints, were left exposed.

Cosletizing. This is a chemical immersion process to protect

external steel parts of an engine from rusting and corrosion. It is not unusual to treat such parts as airscrew hubs, cylinder barrels, induction pipes, brackets, and valve springs in this manner.

Cadmium Plating. This process is applied to studs and nuts, cylinder barrels, valve springs, etc., as a protection against corrosion and rusting. Full details may be found in D.T.D. Specification No. 904. Embrittlement following deposition of cadmium can be serious unless suitable heat-treatment, to expel the hydrogen from the steel, is subsequently carried out. This point becomes even more important if a preliminary acid pickling process has been employed for cleaning the parts, and where possible an alternative process should be carried out.

Enamelling. It is usual to stove-enamel aluminium cylinder heads, carburettor bodies, rocker covers, etc., whilst other parts are sometimes treated with cellulose paint. In either case it is advisable thoroughly to sand-blast the surface before applying the protective coating, in order to ensure satisfactory adhesion.

Full particulars of an enamelling process will be found in Inspection Leaflet No. 404 (A.P. 1208).

It is usual to give the part one or two coats of under-coating enamel, followed by a coat of glossy finishing enamel, the part being heated in the stove between each application, the time and temperature depending on the characteristics of the enamel, but in no case should the temperature exceed 170° C.

Exhaust manifolds, stub pipes, etc., except those made in stainless steel, are protected externally, and several processes are available for this purpose. The drawing will be the guide as to what process is required, and parts, either new or repair, should not be released until the requirements of the drawing in this respect have been complied with.

Calorizing, Fescolizing, and Metallization. Calorizing is a process which has been used for manifolds, but the more generally recognized processes are "fescolizing" and "metallization." The first of these is an electrical deposition of metal, and for exhaust manifolds nickel deposition only is permissible.

With the metallization process the protective coating is sprayed on to the surface of the manifold, and whilst copper, zinc, and aluminium can be satisfactorily sprayed in this manner, only the latter is permissible for manifolds. It is sometimes referred to as "aluminizing."

Before the spraying actually takes place it is necessary to sand-blast the part to remove every trace of scale, grease, or moisture, and then the part should only be handled with rubber gloves until the spraying has been carried out. Adhesive tape is used for protecting threads and parts that are not to be sprayed. The manifold, or stub pipe, is then coated with bitumastic paint, subjected to heat-treatment, and then allowed to cool slowly. The temperatures recommended for this heat-treatment are such that in certain cases a jig may be required to correct distortion. See also D.T.D. Specifications Nos. 906 and 907.

If it becomes necessary to repair a manifold by welding, it is essential that the original protective coating be thoroughly removed to ensure a satisfactory weld. In the case of fescolizing, sand-blasting will

be found quite satisfactory, but in the case of metallization it will be found to be much more difficult, and a check should be made to see that the thickness of the material has not been materially decreased after the aluminium has been satisfactorily removed.

Chromium Plating. This consists of the electrical deposition of chromium on steel parts. It is done for appearance, as a protection against corrosion and to provide a thin surface to withstand abrasion.

With reference to corrosion, chromium is very immune from oxygen attack, but where thin coatings only are deposited, porosity may be experienced and a nickel underlay is sometimes provided.

Chromium is deposited on rocker pads, cones, and similar parts where abrasion is met and it is undesirable to scratch, brush, or polish the mat surface if accuracy is to be maintained. Polishing may easily break through the film, leaving the surface irregular and liable to pick up.

Before dispatching an engine or parts which are unprotected it is usual to apply a coating of Sozol, or, alternatively, temporary rust preventive to specification D.T.D.121.C. This is done either with a brush or by total immersion. In the former case colouring matter is usually added to indicate more clearly that all parts have been adequately protected.

Manufacturing Processes

Many of these processes call for special attention, and a brief reference to the more important of them will now be made. Brazing and silver soldering play an important part in the pipe lines of an engine, as the nipples are usually secured to the pipes by one or other of these methods. Push rod ends and other small parts sometimes depend on soldering for their location.

Brazing. This is dealt with in Inspection Leaflet No. 405 (A.P. 1208), and it is important to note the difference between ordinary and special brazing spelter; the latter having a melting point sufficiently high to enable the finished part to be normalized in the case of dip brazing at any rate, but it should be pointed out that where a nipple is brazed to a steel pipe by heating with a blow lamp, there is a risk of the spelter running during subsequent normalizing. This is due to the fact that Grade A brazing metal has a plastic range very close to the normalizing temperature of the steel. It is not unusual in these cases to normalize the steel tube before brazing, taking care to remove all scale.

As regards inspection, a visual examination should be made, but in addition a part should occasionally be cut right through to ensure that the brazing metal has flowed satisfactorily. See Plate IVa.

The above leaflet also deals with soft soldering and soldering of stainless steel, and indicates the precautions necessary in cleaning the parts before treatment and the precautions to observe during the processes.

When soldering is stipulated in place of brazing, silver solder is normally used.

Acid fluxes should be avoided, but in any case, soldered parts must

be thoroughly washed with an alkaline solution in order to neutralize any trace of acid, which, if not removed, would have a corrosive effect on the parts.

Some people recommend washing the part in boiling water only, followed by an oven drying at 150° C.

Inspection Leaflet No. 405 (A.P. 1208) deals with fluxes and mentions the tests for acidity applicable to the various forms of fluxes.

Suitable tests for jelly base fluxes can only be carried out satisfactorily in the laboratory.

WELDING. This is another process which must be considered, and it becomes important because there is no real method of inspection that ensures a 100 per cent job without destroying the part, although "X" ray has been used in connection with welding in order to check that continuous fusion has been effected all the way along a seam. Parts such as exhaust manifolds are quite unsuitable because of their bulk. Inspection Leaflet No. 145 (A.P. 1208) deals with the subject at length, but the following additional points are important and should be carefully noted.

1. Only those materials specified on the drawing should be used for welding. Normally the two materials to be joined would have approximately the same carbon content, which is usually not more than ·3 per cent. Soft iron wire is used for adding material to the weld. Overheated steel during welding is one of the great dangers, because the crystals can easily be increased in size many hundreds of times, although normalizing will usually restore the structure. For this reason a book record showing that parts have been normalized should be kept.

With a lap weld, a witness on the opposite side of the plate to the fillet is required, and in order that scale shall be avoided, the back of the plate should be protected with a suitable paint.

2. Certain of the austenitic steels are prone to "weld decay" if not dealt with in the correct manner. It would be as well to avoid using this class of material, unless considerable experience has been obtained.

Elements such as Ti, Mo, W, etc., make steel less prone to weld decay, but if doubt exists as to the suitability of a particular class of steel, suitable tests are included in D.T.D. Specification No. 171A. Welding wire should be soft in preference to hard drawn, in order to reduce the risk of cracking resulting from rapid heating.

3. The welding of aluminium, inconel, etc., requires special technique, and only approved filler wires, fluxes, etc., may be used.

4. With certain classes of work it is often desirable to pre-heat the part locally with reduced gas pressure. When welding, the tip of the cone of the flame only should come in contact with the metal, and a neutral flame should be employed, as an excess of oxygen is undesirable.

It should be realized that the temperature of the small white cone at the apex of the flame is probably 3500° C., and there is always a risk of decarburization near the surface of the steel.

5. A pressure test of the part which has been welded should be carried out where the design permits.

When repairing welded parts, such as exhaust and induction manifolds, stub pipes, etc., it is important to remove any protective coatings

such as sprayed aluminium, otherwise the welding wire will not run satisfactorily and a poor weld would result.

The aluminium coating in the case of metallization, and the nickel coating in the case of fescolizing, can be removed by sand-blasting. In the former case, however, it is more difficult, and care must be taken to ensure that the thickness of the material is not impaired.

The repair of a crack by welding necessitates the removal of about ·005 in. to ·010 in. of metal from the surface to ensure freedom from the Al-Fe alloy and somewhat less in the case of the Ni-Fe alloy. The crack should be located at each extremity by drilling an $\frac{1}{8}$ in. hole. The edges of the crack should be chamfered, or better still removed, to form a narrow slot. The crack should then be "tacked" at intervals. If the crack starts from an edge, the first tack should be made there, and it will be found that distortion, as the rest of the seam is completed, will be prevented. The weld should take the form of a regular uniform fillet and on completion should not be filed or dressed in any way. Some manufacturers hammer the weld on a few parts such as induction pipes, where roughness on the inside might be detrimental, but authority in each instance is obtained from the Air Ministry.

Inspection Leaflet No. 39 (A.P. 1208) refers to test samples that have to be made by welders to ensure that they are fully competent at the work. The methods employed to prove that the samples are satisfactory are also quoted.

White-Metalling. Referring now to the process of white-metalling aero-engine bearing shells, connecting rod big end bearings, etc., it is important to realize that the life of an aero-engine, between overhauls, is largely dependent on the ability of the white-metal to withstand the high loads imposed upon it, without undue distress and resultant disintegration, and for this reason every care has to be exercised at all stages in the process of white-metalling. It is not always possible for the ground engineer to obtain actual practical experience of white-metalling, but it is important that he has had the opportunity of supervising or checking every stage of the process, and that he is thoroughly conversant with the details of the procedure prescribed by the engine constructor, and which varies in minor respects only, in the various aero-engine factories. No attempt should on any account be made to white-metal bearing shells unless the full equipment required is available. The tinning of the bearing shell is of the first importance, as the adhesion of the white-metal lining is largely dependent upon this stage. The tinning may have to be done two or three times, the last one requiring the use of the actual white-metal in place of the tin used on the two previous occasions. The following points in the process are also important.

1. Cleanliness at all stages must be strictly observed.
2. Approved fluxes and virgin white-metal only may be used.
3. Pyrometer control of the temperatures of the baths is essential, because they must be maintained within close limits of those specified. Any variations from the correct temperatures might result in either the oxidization of the white-metal, or the risk of working it whilst solidifying.

4. It is necessary to pre-heat the white-metalling jig, together with the rod or bearing shell to be filled. The normal practice is to immerse the parts in scrap metal, maintained at a temperature just below that at which the white-metal is poured. The white-metal should be skimmed before pouring, and an excess of metal in the ladle beyond that required to fill the bearing is undesirable. The molten metal should be vented with a wire in order to remove bubbles from the side of the shell, and additional metal should be added as necessary, to provide for the shrinkage as the white-metal solidifies. When connecting rods have to be re-metalled it is usual to run the old metal out by the total immersion of the part in a bath of molten scrap metal. This ensures that the temperature of the part is closely controlled, and is not brought within the temper brittleness range of the steel. This temperature is about 450° C., but, of course, varies with different high-tensile alloy steels.

5. When it is intended to re-metal bearing shells, a dimensional check should first be made, because the fine tolerance of interference between the bearing shell and the rod often makes re-metalling impossible, due to the fact that after lapping up the joint faces of the two halves of the bearing shell they may be undersize, and become scrap. If they are dimensionally satisfactory they can then be dealt with as previously described, except that a special jig may be required to accommodate them. Slight distortion may be noted when the white-metalling has been completed, but this can normally be rectified by gently tapping with a hide hammer, and the shells re-bedded satisfactorily into their rod.

6. A check to prove that the re-metalling has been carried out satisfactorily is important, and whilst a visual examination for porosity, and blow-holes, which may show up after machining, can be made, this is not enough. Certain types of bearings will respond readily to a ringing test when balanced on the fingers and gently tapped with a hide hammer. At the constructor's works a percentage of bearings are destroyed by subjection to a chipping test. There is, however, another test which can more easily be carried out. The finished bearing is immersed in hot oil for a few minutes and then wiped dry. It is then dusted with french chalk. After the bearing has been allowed to cool, if any cracks are present they will be shown up by discoloration of the chalk where oil has been expelled. The test is equally satisfactory for detecting bad adhesion around the edges of the bearing.

See also Inspection Leaflet No. 138 (A.P. 1208).

7. The fabrications of lead bronze bearings are generally considered to be secret processes and details must therefore be excluded from these notes. The plant is elaborate and complicated, particularly where centrifuged bearings are concerned and the highest technique is called for.

The Cu and Pb, commonly forming a lead bronze lining, do not actually alloy but become a mechanical mixture. Minute bubbles of trapped gas may result in small blow holes being revealed after machining. They are not of necessity detrimental if the metal is otherwise free from cracks and the adjacent metal is sound.

Unsuitable crucibles might result in the presence of undesirable inclusions.

RIVETING. Where two parts are joined together by rivets through which a torque has to be transmitted, the importance of the riveting operation cannot be too strongly stressed, particularly if the parts are subject to suddenly applied loads.

The rivets must be a very good fit in the holes of both parts, and this will necessitate jig-drilling the rivet hole to close limits to ensure accurate spacing.

The two parts must be tightly clamped together to prevent any spewing or extrusion of the rivets between the two faces, and the rivet

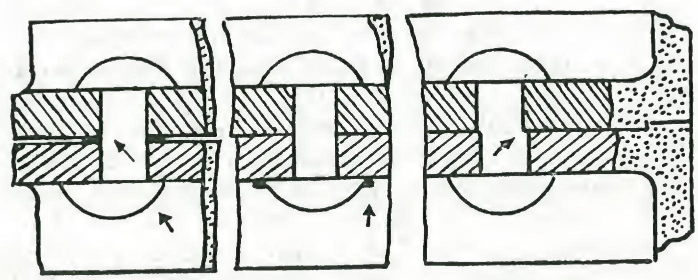


FIG. 2. EXAMPLES OF DEFECTIVE RIVETING

heads must be closed over either by a hand-snapping tool and hammer or a pneumatic hammer.

Care must be taken to see that the heads are square and not deflected to one side, and that there is absence of flash edges or cracks. The rivets should be of the material specified and condition stated on the relevant drawing.

Pressure Tests

Pressure tests are carried out during stages of manufacture as well as on finished parts, and such tests are important, particularly in the case of aluminium castings, where porosity may always be suspected. The nature of these tests should be stated on the type drawings, but it is usual for parts to be subjected to air pressures when submerged in baths of hot or cold water as recommended by the constructors. Paraffin is sometimes substituted for water.

The following information will constitute a guide as to the approximate pressures to which parts are subjected, but in all cases the constructor's recommendations should, of course, be complied with.

Parts that are normally pressure tested at about 20 lb. per sq. in. include—

Carburettor body.
Induction casings.
Front and rear covers.
Cylinder head ports.
Fuel pump bodies.
Fuel pipes.
Primer pipes and rings.

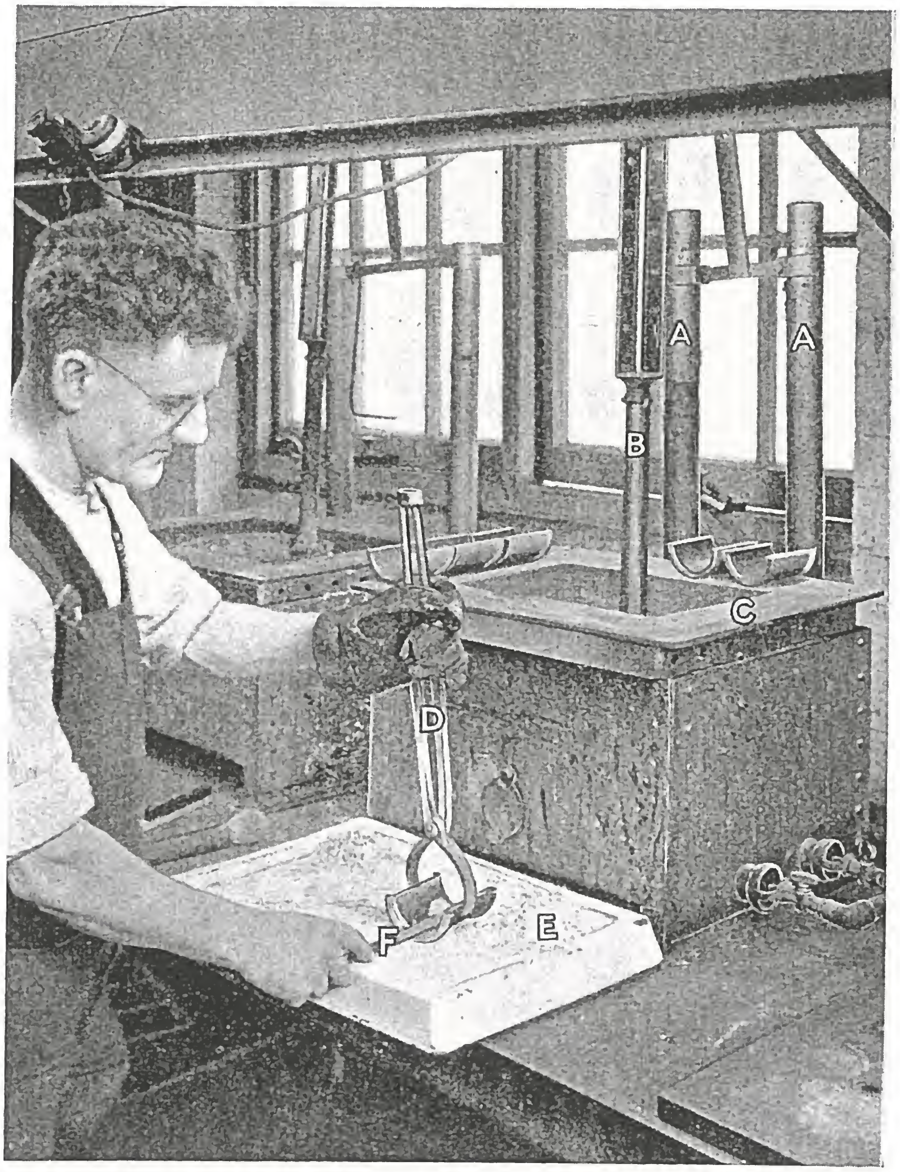


PLATE VA. TINNING A BEARING SHELL PRIOR TO POURING THE BEARING METAL

A = Flues from gas burners.
B = Pyrometer.
C = Gas-fired tin bath.
D = Tongs with locking ring, for handling shell whilst fluxing and dipping.
E = Tray with flux spread all over it.
F = Scalpel for fluxing the surfaces to be tinned.

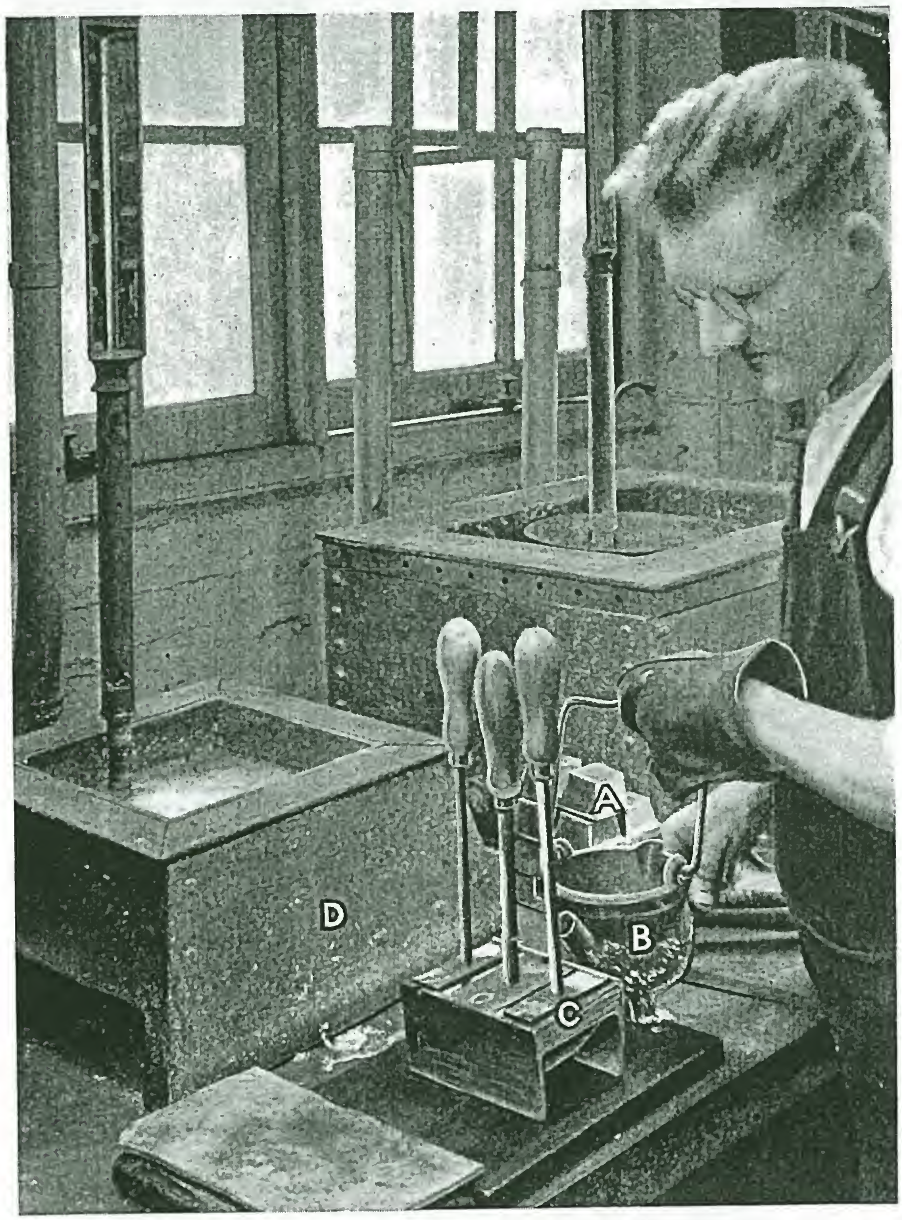


PLATE VB. POURING BEARING METAL INTO THE MOULD CONTAINING THE TINNED SHELL

A = Blocks of virgin bearing metal.
B = Pot with spout from which the bearing metal is poured into the mould.
C = Mould comprising three detachable parts fitted with handles for ease of handling.
D = Gas-fired bath containing virgin bearing metal.

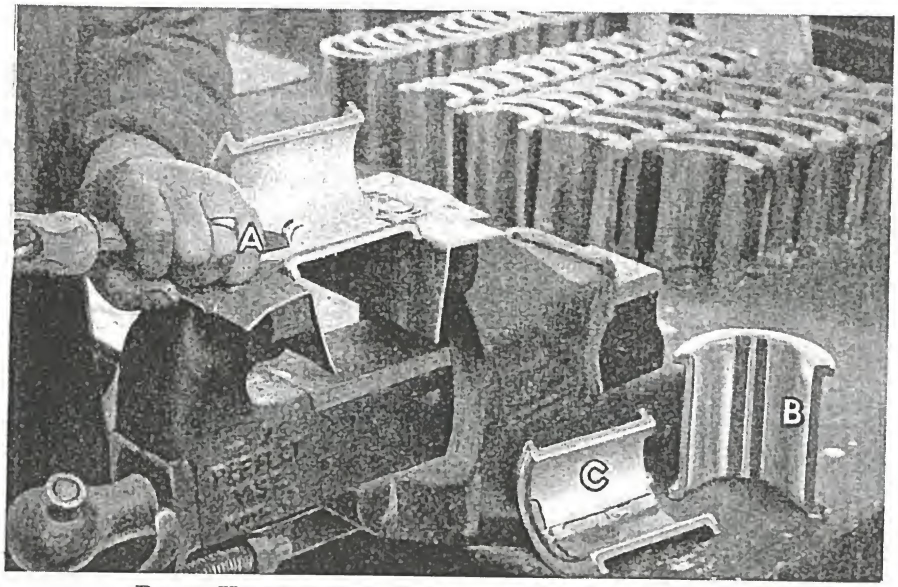


PLATE Vc. CHIPPING TEST ON A FINISHED BEARING

A = Special flat-nosed chisel.
B = A shell which has satisfactorily withstood the test.
C = A shell which has failed.

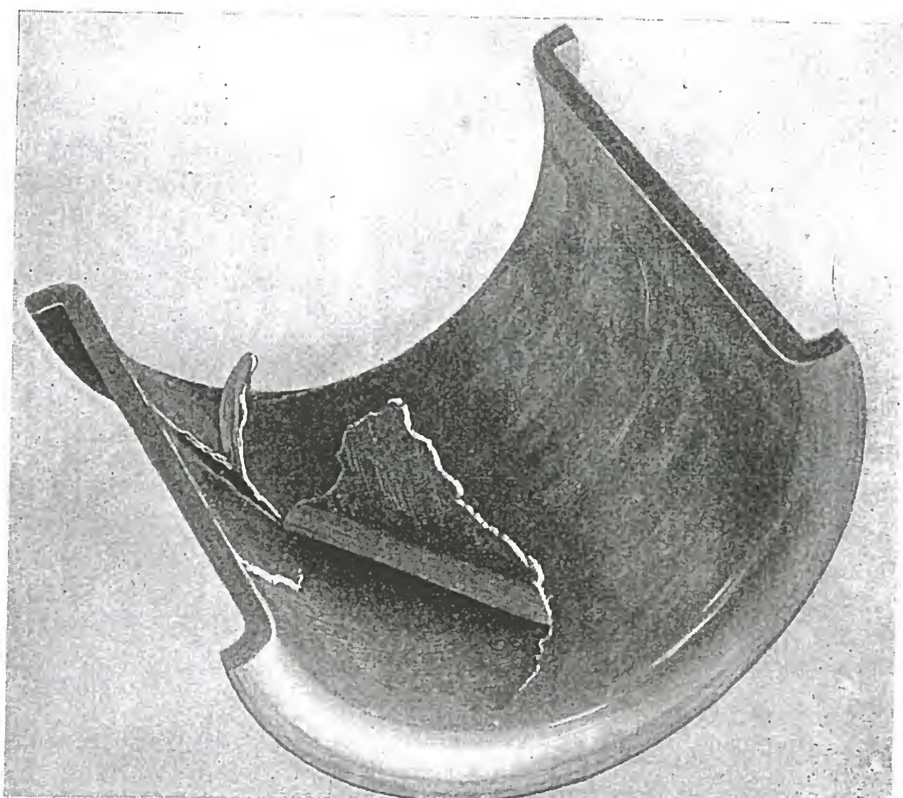


PLATE Vd. FINISHED BEARING SHELL SHOWING FAULTY ADHESION OF THE BEARING METAL

Cylinder water jackets are tested from 25 to 50 lb. per sq. in. Aluminium cylinder headers up to 100 lb. per sq. in., and gas distributors and pipes at 200 to 400 lb. per sq. in. Piston crowns and cylinders complete are tested to from 400 to 600 lb. per sq. in., and a liquid is sometimes used instead of air. The cylinder test would, of course, show whether sparking plug and gas starter valve adaptors, valve seatings, cylinder head joints, etc., were tight. Crankshafts complete with crank-pin plugs are subjected to tests at least 50 per cent in excess of the normal working pressures, and both hot oil and paraffin are used by the various constructors. Sumps, crankcase walls, and pockets, etc., are tested for porosity with paraffin, without pressure; the outside of the walls of parts to be tested are whitewashed, and any paraffin which penetrates, due to porosity, will be indicated on the whitewash.

Caulking, welding, or soldering of aluminium parts in order to attempt to correct a fault is not permissible. Plugging of parts in unstressed positions may be permitted in certain instances, and in such cases a duralumin plug is screwed tightly into a hole countersunk on both sides, and peened over. The diameter of the plug would in no case exceed the thickness of the wall to be plugged. Blow-holes in face joints have, on occasions, been filled with solder, and limited discretion might be permitted in exceptional cases only. Boiled oil has been applied at the constructors' works to parts where slight porosity has been noted, merely as a precautionary measure in case porosity developed under running conditions.

There is a process which is in use by some manufacturers which undoubtedly ensures that the oil finds its way into all the pores of the aluminium. Briefly it is this: The parts to be treated are placed into a container, or tank, which is then sealed and air extracted. Linseed oil is admitted to the tank at a pressure of 70 to 80 lb. per sq. in. for about 30 min. The parts are subsequently removed, and dried in a gas oven for a number of hours at a suitable temperature.

This vacuum treatment ensures that most of the air previously in the pores of the aluminium is removed, the oil taking its place.

It is usual to treat carburettor float chambers with boiled oil as a protection against porosity, but care must be taken to ensure that all traces of oil are removed from the inside of the part by careful cleaning and scraping, and from petrol passages by reamering, etc.

Before effecting pressure tests on headers or aluminium water jackets removed from engines that have had considerable service, it is important to thoroughly dry the part in an oven, as otherwise any porous places might withstand the normal pressure tests without showing signs of leakage, due to the capillary action of any water remaining in the pores.

Balancing of Parts

In order that reciprocating and rotating parts will function satisfactorily when assembled in an engine, it is necessary to ensure that they are correct to drawing so far as their weight and balance are concerned. In this connection, pistons are machined to within specified

weight tolerances, and where, to facilitate manufacture and avoid useless scrap, a manufacturer grades pistons of similar design, it is usual to stamp the crowns with identification symbols in addition to their actual weights, so that when assembling a set of pistons into an engine only those of any one weight grade are selected. It must be clear that the tolerance of weight of a set of pistons will be the same in each engine, although the actual weights of the pistons may vary from engine to engine. For this reason, if it becomes necessary to renew a piston, steps should be taken immediately to ascertain the weight of the rejected one.

Connecting rods are manufactured to weight tolerances and the drawing normally requires the weight of each end to be determined separately in addition to a tolerance on the total weight. This check is made on a machine specially designed for this purpose.

Rotating parts such as crankcases of rotary engines, crankshafts, rotors, etc., are balanced statically, that is to say, they will remain at rest in any position when mounted so that they are free to rotate about their own axes.

It is also necessary to ensure that crankshafts, supercharger rotors, etc., are also in dynamic balance, for whilst a part may be in static balance when stationary, it may be out of balance when rotated, on account of the variation in density of the material or uneven distribution of the mass around the centre of rotation resulting in the presence of couples which, if not corrected, would cause excessive vibration. Constructors are normally equipped with suitable machines for checking dynamic balance. With particular reference to rotary engines, all parts of the cylinder assembly must of necessity be manufactured to close weight tolerances to ensure freedom from vibration under running conditions; and when renewals are made it is essential to see that the new part is of similar weight to the one it replaces. In the case of cylinders, these are normally checked on a machine which takes into consideration both weight and centre of gravity. The cylinder is mounted horizontally on the horizontal arm of a special balance. A shoulder is provided on the arm so that the cylinder is set up at a radius from the fulcrum corresponding to the normal position of the cylinder when fitted on its crankcase. Adjustment is effected by removing metal from one of the fins.

Heat-treatment

The ground engineer must understand the various heat-treatments that material has to undergo, in order to transform it into the most suitable condition for use in an aero-engine, and we will deal first with the ferrous materials.

The ground engineer must understand what is meant by the term "upper critical point." This is the temperature at which a steel, on cooling naturally, commences to precipitate the carbon previously in solid solution in the form of cementite (iron carbide Fe_3C). The iron previously in "gamma" form becomes known as "alpha" iron.

Any change in constitution or rearrangement of the atoms constitutes a critical point. In most steels there are upper and lower

critical points, but iron containing ·89 per cent carbon has only one. In this connection we may mention that with a straight carbon steel the upper critical range falls between 900° C. and 700° C., according to the amount of carbon present in the steel. With a critical point at 900° C. there can be no carbon present, but by adding carbon you progressively lower the upper critical range temperature until at 700° C. the carbon present is ·89 per cent. With alloy steels the temperatures are some-

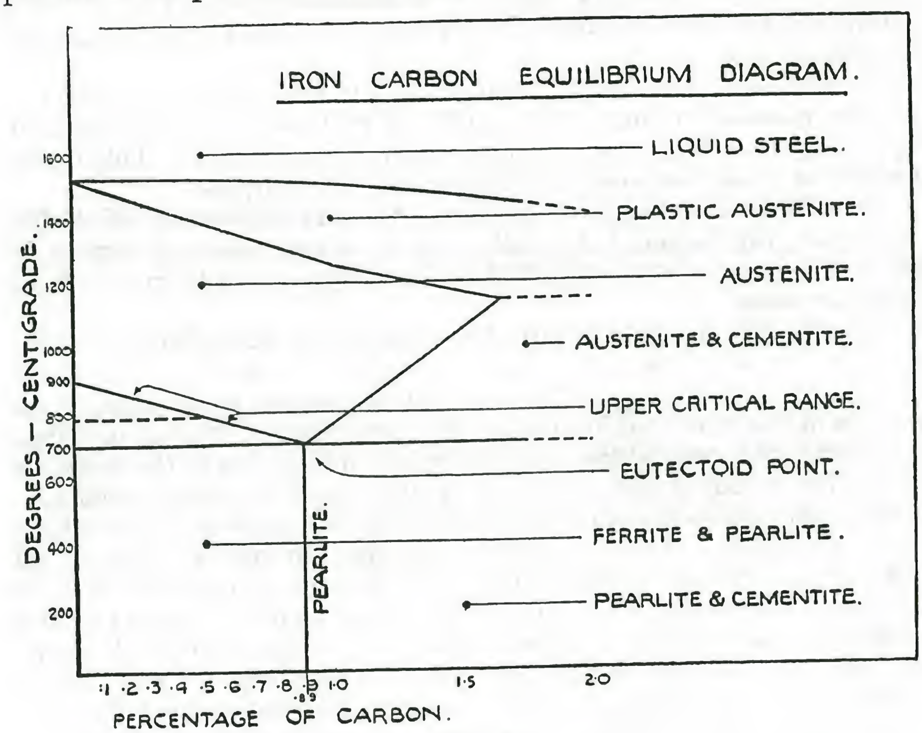


Fig. 3

what lower, and in any case the characteristics of each class of steel must be ascertained before correct heat-treatment can be carried out. A further study of this matter can be made by referring to textbooks on the iron carbon equilibrium diagram. A sketch of that part of the diagram which is required in connection with steels for aero-engines is shown in Fig. 3. Definitions of the terms will be found in the glossary at the end of these notes.

Annealing is often called for after a certain amount of cold working, that is to say, work done below a red heat, resulting in the material becoming considerably harder. Annealing is carried out by heating the part in an oven, and leaving to cool as slowly as possible. The temperature and time at which the part is maintained in the oven depends on the class and bulk of the steel, and the nature of the stress to be relieved. If the temperature is just above the upper critical range the structure of the steel is also refined. Annealing results in a finer structure than after normalizing, owing to the greater length of time in which the crystals have to rearrange themselves.

Annealing is also done to relieve internal stresses set up as in the case of steel castings.

Close annealing is a term applying to parts which are placed in closed tubes, or containers, for the annealing process, with the object of preventing the parts coming into contact with oxygen from the surrounding air, and thus avoiding the formation of scale and the risk of decarburization. Another process with the same object consists of purging the furnace with special non-oxidizing gas.

When annealing stainless steel, temperatures may be as high as 1100° C., but not less than 1000° C., followed in some cases, by rapid cooling in order to avoid weld decay, which may occur if rapid cooling from between 800° C. and 400° C. is not carried out.

Normalizing becomes necessary when the material has a coarse crystalline structure, as in the case of a forging, a part that has been hot-worked or welded. To normalize a part it is necessary to heat the steel to a temperature not exceeding the upper critical range by more than 50° C. It is maintained at that temperature for about $\frac{1}{4}$ hr. and cooled freely in still air. This treatment has the effect of taking the cementite back into solid solution, and allowing it to crystallize out again in a finer state of division, and with a much reduced grain size.

The heat-treatment of a steel consists of hardening, followed by tempering. The hardening is carried out by heating the steel to its normalizing temperature, followed by immersion in water, oil, or air, according to the class of steel and specification requirements. Most of the carbon in the iron is thus maintained in solid solution at ordinary temperatures. Tempering is carried out by heating the steel to a temperature below the critical range, say between 550° C. and 650° C. This has the effect of altering the degree of hardness and brittleness.

To make this point clearer, a set of tempering curves is included, for general guidance only, representative of a CrNi steel of the S.11 class, and it will be understood that curves for other steels will vary according to the carbon content and the presence, or otherwise, of alloying elements. (See Fig. 4.)

These curves are compiled by carrying out a series of mechanical tests on a number of similar test bars, each one hardened in a similar manner, but tempered at different temperatures.

An examination of the curves will show that with this class of steel the impact figures are low at tempering temperatures between 250° C. and 450° C., and that high maximum stress figures can only be obtained at the expense of the impact values. In other words one has to make a compromise in order to meet specification figures, and this can only be done by a careful selection of the tempering temperature.

If the temperature at which normalizing or heat-treatment is carried out exceeds the upper critical range by more than 50° there is a risk of burning the steel, in which condition the crystal grains are split apart and cannot be restored other than by re-melting.

The following points may be informative in effecting heat-treatments—

(i) Large forgings and stampings should be amply supported

and the furnace should be charged so that all parts get uniform heating.

(ii) With large forgings mass effect must be considered and the period of heat-treatment should commence only when the whole has attained the required temperature.

(iii) Mass effect must also be considered when quenching and local heating of the coolant should be avoided by agitation or other means.

(iv) Quenching cracks accrue at sharp corners so these should be avoided.

(v) Long forgings, such as camshafts, are often cooled vertically to minimize distortion, whilst large light gears may be quenched under a press for the same reason.

(vi) The presence of scale in irregular patches on the surface of a part when quenching, may result in only partial conversion of the steel from Austenite to Martensite, the patches under the scale being either Sorbite or Troostite. Such a condition might set up internal stresses sufficient to start a crack. Scale formation can be reduced by a coating of Graphite whilst deposition of Ni practically eliminates the trouble.

Case-hardening is carried out to obtain a material with a very hard, good-wearing exterior, or case, together with a very tough interior, or core, which will resist shock. The steels used contain between ·1 and ·2 per cent of carbon. In addition, certain alloys are added if the core is required in a stronger condition.

Nickel enables oil quenching to be substituted for water, and this less drastic treatment not only minimizes the risk of surface cracks appearing after grinding, but reduces the rejections due to distortion.

The more important points in the process of case-hardening and requiring attention are—

Carburizing Compound. A large variety of substances is used, and apart from proprietary mixtures, such as casenit, etc., there are charcoal, barium carbonate, and charred leather.

The compound should be free from dust and sulphur, and should not produce any ash which fuses at the carburizing temperature.

The rate of producing carbonaceous gases varies with the various compounds, and experience only can determine the right temperature for the oven and the period that the part has to remain there.

Nickel steels take longer than plain carbon steels for the occlusion of an equivalent amount of carbon.

Preparation of the Part to be Cased. The surfaces that require hardening should be thoroughly cleaned, and those that do not require hardening should be protected either by a coating of suitable enamel, copper deposition, asbestos string, clay, etc.

The articles should be so packed in metal boxes that there is at least 2 in. of carburizing material between them and any part of the box or lid.

The lid should be luted with clay to prevent gas leakage.

Carburizing. The box is heated up to the required temperature and retained at that temperature for the specified period. As a guide

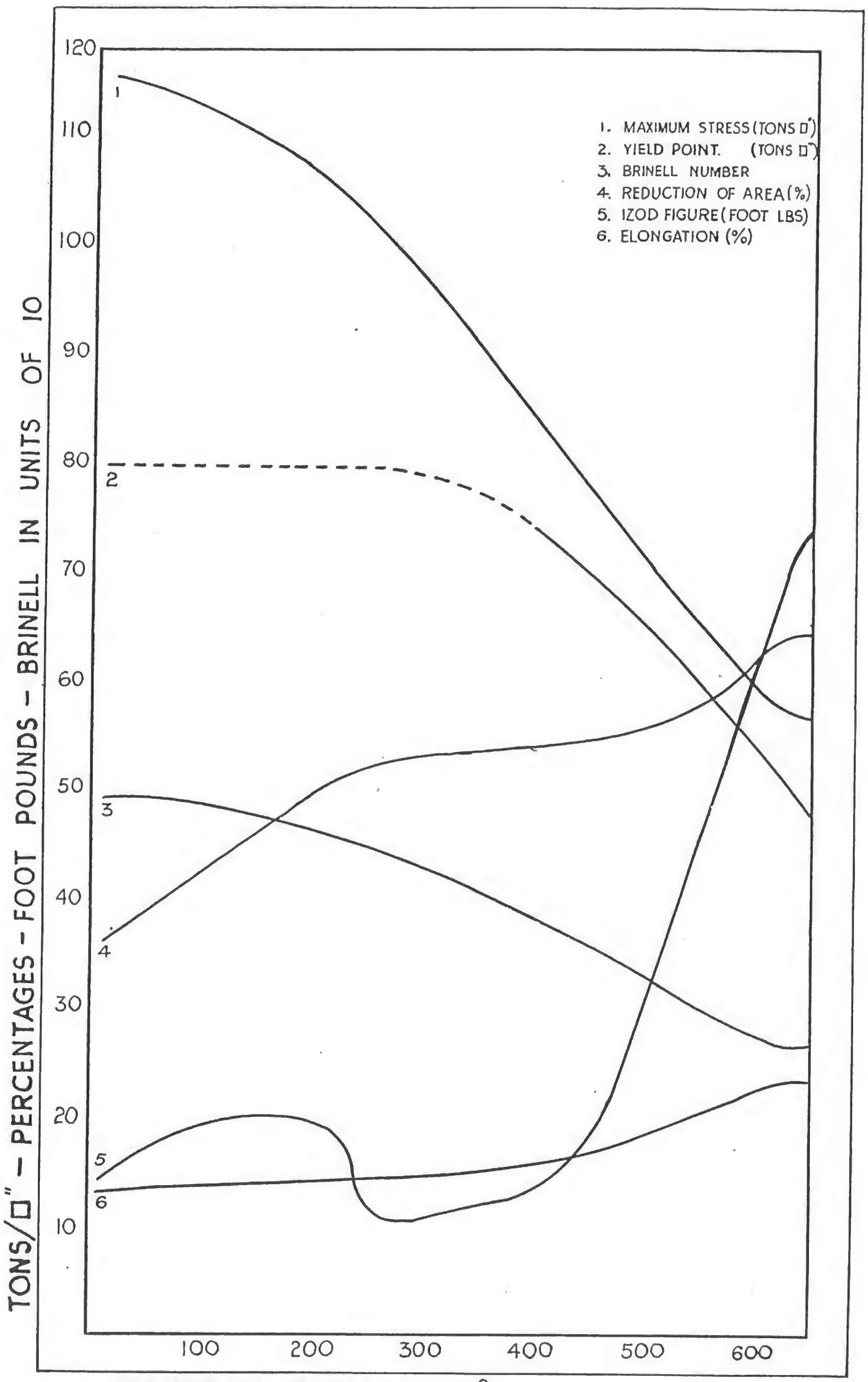

1. MAXIMUM STRESS (TONS □")
2. YIELD POINT. (TONS □")
3. BRINELL NUMBER
4. REDUCTION OF AREA (%)
5. IZOD FIGURE (FOOT LBS)
6. ELONGATION (%)
TONS/□" – PERCENTAGES – FOOT POUNDS – BRINELL IN UNITS OF 10
120
110
100
90
80
70
60
50
40
30
20
10
100
200
300
400
500
600
TEMPERING TEMPERATURE °C.

FIG. 4

to this, it may be taken that a depth of case of 1 mm. (·040 in.) would be obtained in from 4 to 6 hours, the temperature being about 900° C.

The box is then allowed to cool slowly in order that the merging of the case into the core may be as complete as possible, thus avoiding the hard line of demarcation that is occasionally noticed due to an abrupt transition. The risk of "exfoliation" or "peeling" of the case is also minimized.

Heat Treatment. It is desirable to clean the parts after removal from the box, and this can be assisted by sand-blasting.

The long heating in the box at an elevated temperature results in the production in the core of a coarse structure. It therefore becomes necessary to refine the core by re-heating the material to a temperature about 900° C., and quenching. This temperature, however, is much too high for the case, and thus a second heat-treatment at about 760° is required, after which the material is again quenched. This second heat-treatment and quenching also improves the condition of the core. The refining process does not require any period of soaking before quenching, and even the final hardening does not require any undue soaking.

Test Bars. Two bars of material, identical to the parts, will be included in the box. After carburizing, one of the bars will have the case removed, and must then be put back with the parts for heat-treatment; after which a standard test bar will be prepared from it and the physical properties, which would be representative of the core, ascertained.

The other test bar will be fractured and examined. The core should show a close-grained fibrous fracture, and the case a characteristic silky smooth appearance.

Straightening. Slight distortion can normally be rectified during the grinding process, and it is undesirable to resort to straightening because there is no guarantee that any setting will be permanent, and, furthermore, visual examination might not be sufficient to detect any cracks which might easily commence.

Some discretion might be permitted by the constructor in certain cases if followed by a magnetic test.

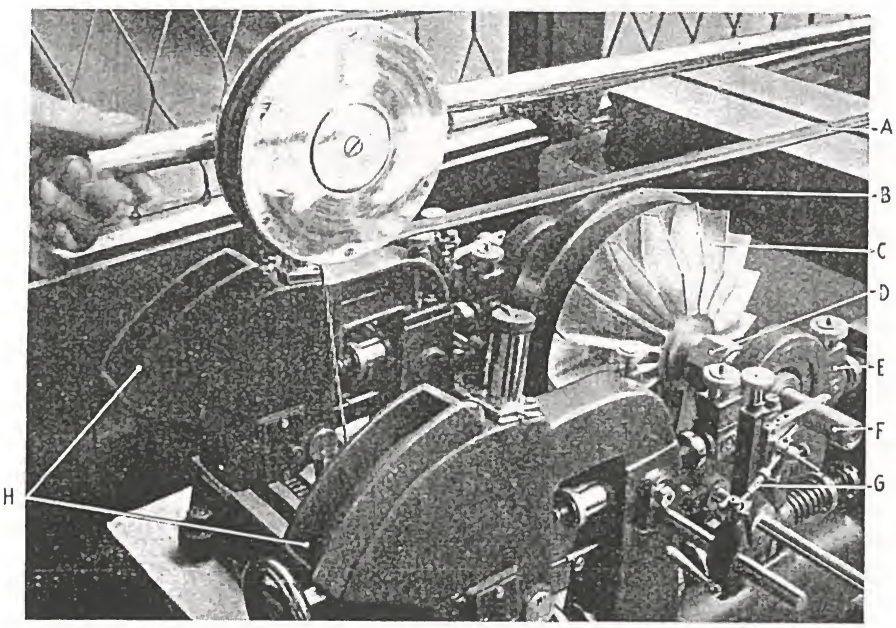
For examples, the straightening of a soft shaft with an integral case-hardened gear at the end, or the straightening of parts prior to heat-treatment.

Camshafts for in-line engines which become bowed are sometimes straightened after annealing at from 150° to 200° C. It may be necessary to deflect the centre of the shaft about three times the amount to be corrected.

Nitrogen Hardening. This is a form of surface hardening which is carried out to a limited extent on crankpins and journals, the inside of cylinder barrels, valve stems, etc., and parts where local shock loadings do not occur.

The steel used for this process is of special chemical composition, and may include 1 per cent of aluminium but no nickel, as its presence would reduce the impact value. The steel is heat-treated in the usual manner prior to surface hardening by this process, and parts which

PLATE VI. INCLUSIONS IN STEEL
(As seen on a finished surface under a 5 to 1 magnifying glass)



By courtesy of *Messrs. Armstrong-Siddeley Motors, Ltd.*

PLATE VII. IMPELLOR BALANCING MACHINE

A is a rotating belt providing a friction drive to the mechanism, when lowered to come into contact with the fly-wheel *B*.
F is a rotating shaft, which is mounted on ball bearings and carries the impellor *C*. The nut *D* secures the impellor on the shaft. The mechanism *E*, comprising the shaft and its bearings, is spring mounted, and any error in balance is transmitted *via* the mechanism *G* to mirrors, which reflect beams of light on to the two scales *H*.

have not to be hardened are protected in a similar manner for case-hardening, except that copper plating is unsatisfactory. The process, briefly, is to pack the parts to be hardened in an air-tight box, through which ammonia gas is passed. The box is maintained at a temperature between 470° and 500° C. and the depth of penetration is dependent on the class of steel and the time the process is in operation. If the part is in the oven for 75 hours penetration of from ·010 in. to ·015 in. deep may be expected.

The following points should be noted—

(i) The box must be free of air otherwise the uniformity of penetration cannot be ensured.

(ii) Part machined, heat-treated parts can be nitrided without risk of distortion, it being only necessary to leave a grinding allowance on the surface nitrided.

(iii) The process can be repeated on the same part without detriment. This might be necessary on a crankshaft, if a crankpin became damaged and required reducing in diameter.

(iv) Sn offers protection against penetration of the oven gas.

(v) Steels, except those containing Ni, respond in some degree to hardening by this process.

(vi) Nitrided surfaces, if lubricated, are free from lead attack.

(vii) Parts should be supported in the oven at positions where penetration is not required.

Heat-Treatment of Non-Ferrous Materials. Aluminium is probably the only metal under this heading which is subjected to heat-treatment to improve its physical properties. The improved properties are dependent largely on the presence of one or more of the following alloying elements: Cu, Ni, Mn, Mg, Fe, Ti, etc.

It has of course been current practice for many years to "Season" castings, both large and small, at various stages of manufacture by annealing, with a view to relieving casting stresses and eliminate the possibility of distortion which might otherwise develop. Aluminium with a high silicon content has considerably helped the foundry in eliminating some of their difficulties in regard to intricate castings and has also provided material with properties offering considerable resistance to corrosion. Magnesium alloys, whilst being very light and consequently useful in aero-engines, are not resistant either to salt water or atmospheric corrosion. The properties can be much improved by a high temperature treatment.

Aluminium alloys are now obtainable in the forged and wrought condition, but no matter in what form the material is available, the physical properties are low and unless it is subjected to some form of thermal treatment to improve these properties, is unsuitable for the manufacture of highly stressed parts, such as pistons, connecting rods, cylinder heads, crankcases, etc.

The various elements or hardening constituents added to aluminium can be taken into solid solution at elevated temperatures in the same way that carbon and other elements can be absorbed in steel. There is however this difference. On quenching steel the solid solution is maintained at room temperature, but in the case of aluminium alloys they

are not stable. In addition, super-saturation may occur as the part or material cools and precipitation of the particular alloyed constituent may result. In other words aluminium can absorb and retain more of the constituent at elevated temperatures than at room temperature.

The precipitation or "age-hardening" takes place very slowly at room temperatures but can be accelerated with some alloys if subjected to low-temperature treatment between 100° C. and 200° C., after which the material becomes appreciably harder and the physical properties are much improved.

The high temperature treatment, sometimes called normalizing, can be done either in an electric furnace or a salt bath. The temperature control is important, particularly in the case of magnesium alloys and duralumin, as the temperatures approach closely to those of the fusion point of the constituents. The age-hardening can be carried out in a gas-fired oven. With regard to the use of a salt bath, every care must be taken to see that the part is entirely immersed and heated uniformly.

Approximate heat-treatments for several aluminium alloys in general use, are given below.

Duralumin: Soak from 480° C. to 500° C. for from a quarter to three hours, according to the size of the piece and quench in water or oil. Age-harden naturally for four or five days.

Notes. (i) Accelerated age-hardening is not permitted. It would respond to this treatment but if carried out too quickly, that is to say at too high a temperature, would leave the material brittle.

(ii) The temperature of the piece must be not less than 480° C. at the time of quenching, so the temperature when it leaves the oven must be high enough to allow for any drop in temperature during the transfer.

(iii) The upper temperature must on no account be exceeded.

(iv) Any cold work after heat-treatment may entail a re-heat-treatment of the piece.

(v) If a salt bath is used, the pieces must be thoroughly washed in water afterwards. See also Inspection Leaflets Nos. 408 and 414 (A.P. 1208).

"Y" Alloy: Soak from 500° C. to 520° C. and quench in boiling water followed by natural ageing for four or five days or accelerated ageing by immersion for two hours in boiling water.

Note. Physical tests can only be made on completion of the full period of ageing of the test bar.

Hiduminium: Soak from 500° C. to 535° C. for from two to four hours and quench in water. Age-harden from 155° C. to 175° C. for from fifteen to twenty hours and quench in water.

Note. The temperatures and times quoted will vary according to the particular variety of this material. It will also be noted that low temperature treatment is necessary, as the material does not age-harden quickly enough, naturally.

Material to R.R. Specification No. 50 (D.T.D. 133B), which is one of the Hiduminium series, is used for sand and die castings and attains its physical properties with low temperature treatment only, thus avoiding dangers of cracking and distortion associated with the high

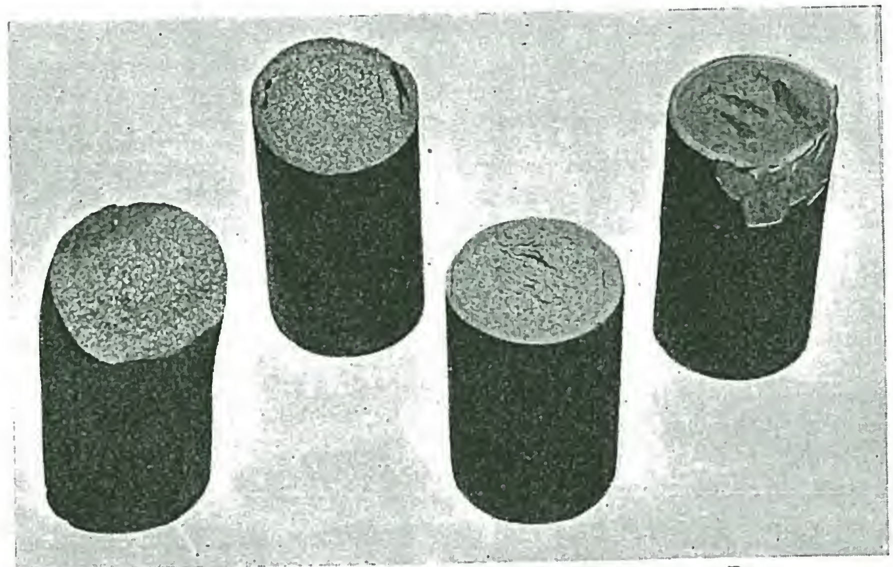
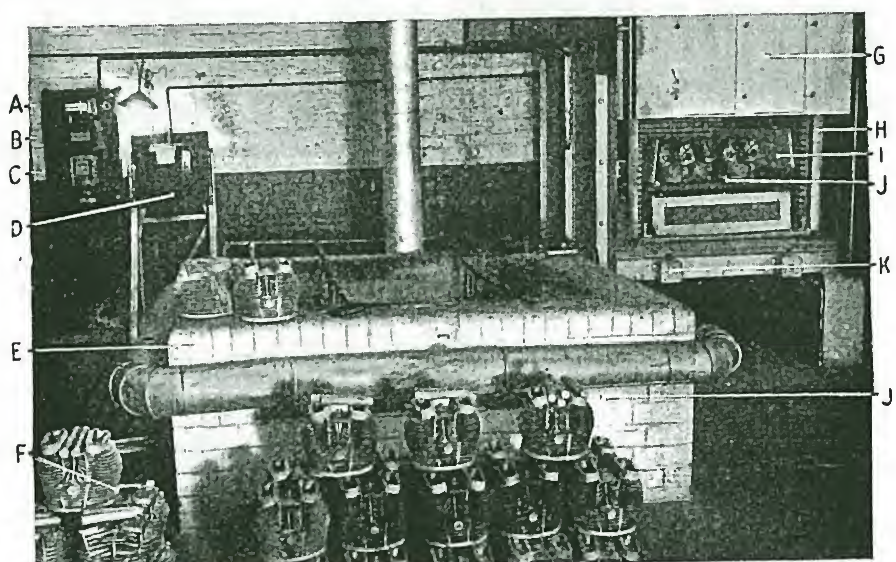


PLATE VIII. FRACTURED TEST BARS OF STEEL TO BSS. 2.S.14 SHOWING STAGES OF CASE-HARDENING

A = Normalized bar as received. (Note coarse structure.)
B = After carburizing at 910° C. for 8 hours and cooling in box.
C = After refining the core at 900° C. and quenching in cold water.
D = After second heat treatment at 770° C. and quenching in water.



By courtesy of *Messrs. Armstrong-Siddeley Motors, Ltd.*

PLATE IX. HEAT TREATMENT OF CYLINDER HEADS

A = Foster pyrometer. (Thermo couple in top of furnace.)
B = Wild Barfield temperature control.
C = Venner time switch.
D = Cambridge recording pyrometer. (Thermo couple in base of furnace.)
E = Water bath for quenching parts after heat-treatment.
F = Cylinder head, showing cast on bridge for controlling distortion.
G = Wild-Barfield electrically-heated furnace.
H = Electrically-heated elements in walls and door of furnace.
I = Asbestos sheets to eliminate radiation from the elements.
J = Test bars (two with each head).
K = Switches, which start circulating fan in top of furnace, on closing door.

temperature treatment. The heat-treatment is to soak at from 155° C. to 170° C. for eight to sixteen hours, followed by quenching in air or water.

Close control of all temperatures during heat-treatment processes should be maintained by means of pyrometers, preferably of the automatic recording type. All pyrometers should be checked by Sentinal salts or master pyrometers at regular intervals. All records of heat-treatment should be correlated with the various batches of parts heat-treated, in the same way that test bars must be correlated with the part, or batch of parts, heat-treated. (See Plate IX.)

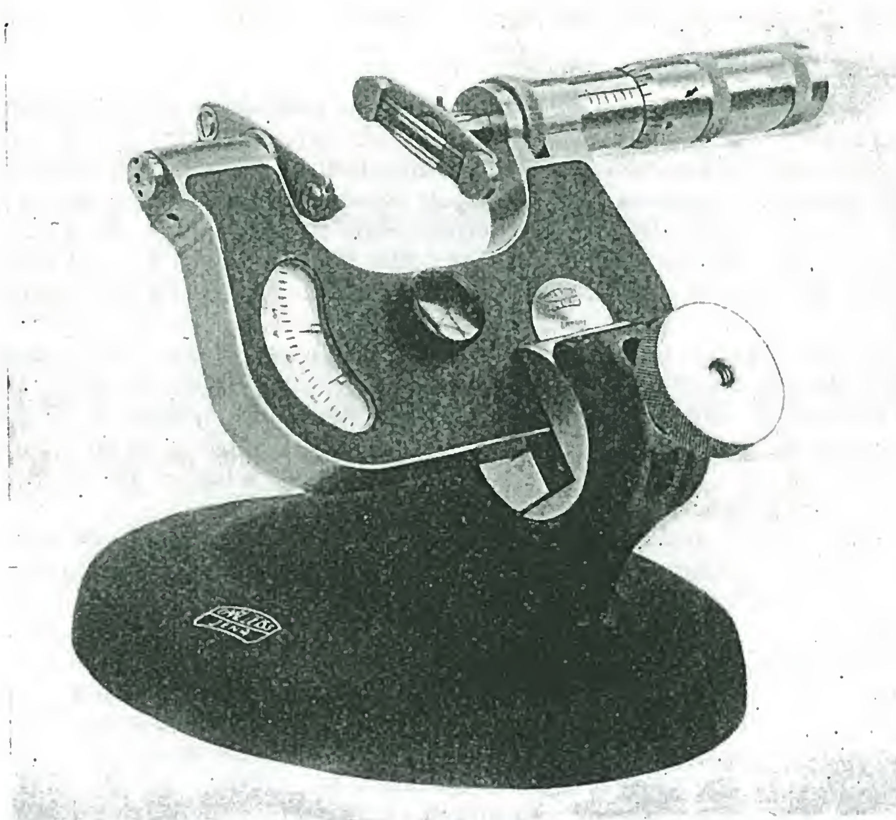
Dimensional Check

We now come to the inspection of parts, both during manufacture and prior to assembly in an engine, and it is important that the ground engineer has had experience in the manipulation of the various measuring instruments such as the micrometer (reading in fractions of ·001 in.), the Vernier Height Gauge, the Vernier Slide Caliper Gauge, the Depth Gauge, the Dial Indicator, etc., and the use of gauges for checking linear dimensions and plain screwed diameters. He should be familiar with English and metric systems of measurement, and understand the tolerances quoted on drawings. He should be reasonably conversant with the limit system applicable to the particular engine in which he is interested. Some manufacturers have their own system of limits for plain dimensions, which in most cases will be found to be an amplification of the Newall system, whilst others have adopted the British Standards Institution system of limits and fits.

The Newall system is founded on a "hole" basis which provides for A and B classes of hole over a range of from 0 in. to 6 in. Various fits are obtained by mating these holes with shafts in F, D, P, X, Y, and Z classes. The various combinations providing force, driving push, and running fits. The system is somewhat restricted in range as compared with the B.S.I. Limits and Fits for Engineering (Report No. 164, 1924). The latter provides a greater range on the nominal sizes and the tolerances applied to each. The main principle is, however, the same in that the various fits are obtained by varying the fits of the shaft to a given set of holes. Limits are referred to as "unilateral" and "bilateral." The unilateral system has the nominal size as the low limit of the hole and the tolerance is all in one direction, whereas with the bilateral system the nominal size lies between the high and low limits of the hole, the tolerance is therefore in both directions. This system provides twenty-eight varieties of fits as compared with eleven sizes in the case of the Newall system.

The more important functions of a view room will now be mentioned.

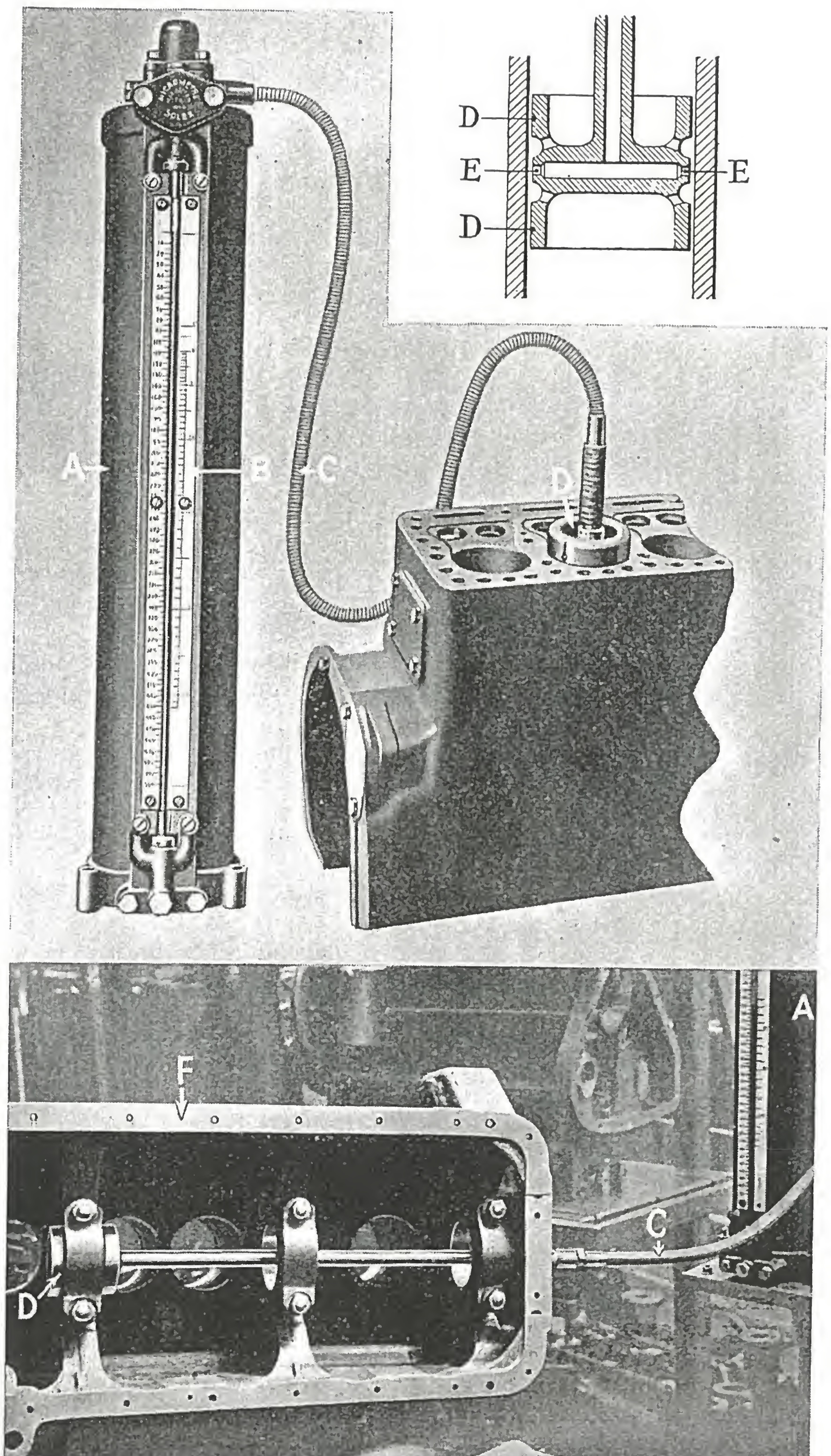
1. Special gauges and fixtures, suitable for checking the major components, must be provided to ensure interchangeability of parts. These fixtures, together with the surface table on which they are to be used, must be accurate to within the limits of the work to be checked. Standard "go" and "not go" plain and screw gauges must be provided for all other dimensions to ensure conformity to the respective drawings. (See Notice to Aircraft Owners and Ground Engineers No. 16 of 1932.)



By courtesy of *Messrs. Alfred Herbert, Ltd.*

Plate Xa. The Zeiss Micrometer

Fitted with "needles" for measuring effective diameters of screw threads.



By courtesy of *Messrs. Burton Griffiths & Co.*

PLATE XB. SOLEX PNEUMATIC MICROMETER

A = Pressure controller
B = Graduated scale
C = Air pipe to gauge
D = Solex plug gauge
E = Air leak apertures
F = Crankcase and bearings

Where parts are given protective coatings the thickness is increased about ·0003 in. in the case of cadmium plating and about ·00125 in. in the case of cosletizing. BSF and BA studs and nuts so treated are sometimes checked to Inspection gauges, prior to treatment, which have been set ·001 in. under the low limit on effective diameter for studs and from ·001 in. to ·002 in. above the high limit on effective diameter for the nuts. These variations from the limits specified in the B.S.I. reports take care of the extra film of metal after the protective treatment.

In a fully equipped Inspection organization there are "Workshop" gauges which are so dimensioned that the work they produce will pass the "Inspection" gauges when checked in the view room. There are also "Master" gauges, which are only used, as required, for reference purposes when the Inspection gauges are suspect or a new gauge has to be put into use.

For checks on gap gauges and length measurements the master normally consists of a set of Johannsen slip gauges, which offer a more accurate means of measurement than a micrometer since there are no screw pitch errors to contend with or other inaccuracies due to moving parts.

Slips are checked for flatness and parallelism on special highly sensitive machines as well as for variations from their nominal sizes, to an accuracy of ·00001 in.

When building up odd sizes a number of slips may be used in combination by "wringing" their plain surfaces together. The method of wringing consists of placing one slip crosswise on another and then twisting them until their edges lie parallel, but on no account should any pressure be applied.

The slightest amount of dust or grease between the slips will prevent them wringing together satisfactorily.

It is a requirement of the Air Navigation Directions that any departures from the type drawings shall be recorded in the form of concessions, and all such concessions must be filed for future reference during supervision by the authorized representative of the Air Ministry.

2. The finish of stressed parts is of first importance, as tool marks, sharp corners, etc., on parts, when subjected to load running, might develop into fatigue cracks owing to concentrations of stress. Sharp corners at the radii of gear teeth, etc., should be carefully radiused off with a fine file. Rough edges and ragged threads should be removed from all parts, as this "swarf" might otherwise do considerable harm if such parts were built into engines. Chatter marks on gudgeon pins and the like can be detected by rubbing the surface with a split phosphor bronze bush, which will cause the high spots to be seen. This fault may be associated with the speed of the grinding wheel feed or lack of rigidity of the machine or fixture.

Finished steel parts must be cleaned, dried, and immediately protected against rust formation. Parts should never be handled. Chemical cleaners require skill in operation on this account. Corrosion of surfaces has been attributed to failure to entirely remove traces of lubricant used on a machine during machining of the part.

3. Many parts have their weight stamped on them, and others the cast and serial number, whilst nearly all parts have their part number and inspector's stamp. The importance of lightly but legibly stamping these items in the positions indicated on the respective drawings is particularly stressed in Inspection Leaflet No. 128 (A.P. 1208).

Acid and electric etching are carried out on certain case-hardened parts and those which would be liable to damage if the marking was stamped or rolled on. In the case of electric etching, care is required to see that the impression from the pencil is not deep enough to produce local burning of the material.

4. Finished heat-treated and case-hardened parts are normally hardness tested as a routine procedure, Rockwell or Vickers Diamond point machines being employed. The latter is preferable when the impression has to be made on a working surface, as it is smaller than the Rockwell impression, but in either case it is desirable to lightly stone the locality afterwards. When it is possible to check the hardness of a part adjacent to the working surface, this should always be done. When the test is made the part should be adequately supported and the surface to be tested square with the platform. Full particulars of hardness testing machines and their application will be found in Inspection Instruction No. 406 (A.P. 1208).

5. Certain parts which are manufactured for spares may subsequently require additional work on them before they are suitable for building into an engine. Others may be made oversize or undersize on a particular dimension to accommodate a worn mating part which has been rectified. Thus a re-metalled bearing may be left small in the bore to accommodate a ground journal or pin. Oversize connecting rod bushes are often required and oversize piston rings are fitted to cylinders which have been ground in the bores. This matter is, however, dealt with fully in Inspection Leaflet No. 120 (A.P. 1208).

The ground engineer should be familiar with inspection checks peculiar to certain parts, and I will cite some of them.

1. In-line crankshafts are checked on knife edges for static balance, and with a dividing head for accuracy of the angles of the throws. A check is also required for bowing, the crankshaft being supported on "vee" blocks and "clocked" on the journals, and it must be remembered that the errors shown by the maximum and minimum readings on a dial indicator are double the actual errors. Single-throw crankshafts are mounted on knife edges and balanced with a bob weight suspended from the crankpin.

2. Valve springs should be checked for deflection under loads equivalent to the closed and open position of the valve when assembled to the cylinder.

3. Cams would require checking for contour lift and distortion.

4. Ball bearings would be checked for end float if the relative drawings specify a limiting dimension, otherwise end float is not normally considered of vital importance.

5. Connecting rods would be checked for accuracy of centres, parallelism and twist of wrist pin and gudgeon pin bores, and in many cases the weight.

6. Gas and scraper rings are thoroughly inspected before delivery to the engine builders and rings from engines undergoing repair or overhaul should, as far as possible, be tested in a similar manner at the engine builders prior to the reassembly in an engine. The tests normally carried out on a new ring are as follows—

(i) Radial Loading. This is a test of cylinder wall pressure and has a very important bearing on the oil consumption of an engine. It is ascertained by measuring the load required to just close the ring. It is applied diametrically when using the "Brico" machine, and tangentially when the ring is held vertically in a vice with the gap horizontal, by attaching a load to the end of a thin flexible greasy wire passing around the circumference of the ring.

(ii) Circularity. Each ring is fitted into a cylinder with a smooth and accurate bore. A strong light is placed behind the ring and any places where contact is not being made with the cylinder wall, permit light to pass and rejects the ring.

(iii) Squareness. Each ring is placed on a surface plate and, if it does not lay flat, is set by hand. The contact or rubbing face is then checked against a vertical member or gauge.

(iv) Gap. The free gap should conform reasonably to drawing requirements in the case of used rings. The nominal gap is checked with the ring fitted squarely in a gauge of nominal dimensions. For new rings the minimum of gap filing should be permitted. When dealing with used rings, which may be ·005 in. or ·010 in. oversize on nominal dimensions, an appropriate ring gauge would be required.

7. Gear wheels are checked on a rolling jig embodying master gears for meshing purposes. The teeth can also be checked by direct measurement with a tooth vernier, or on the more elaborate gear measuring machine.

The airscrew shaft gears and the crankshaft pinion, comprising the reduction gear, are usually run together on a special fixture before assembly on an engine. This preliminary surfacing of the teeth should be carried out in the normal direction of rotation, and parts so dealt with should be grouped in sets.

Note. Most of the inspection checks referred to above involve the use of special jigs and equipment. The engine handbooks usually give full information on these matters and should be obtained for reference.

Inspection should be directed to eliminating faulty work as early as possible and thus avoid the cost of the various machining and fitting operations that would be wasted if the part was allowed to go forward undetected. Errors occurring as the result of wear and tear of machinery, worn dies, cutters, and patterns should always be looked for, and action taken to rectify the moment a fault from any of these causes is noted.

The inspection of rectified or repaired parts should be carried out exactly the same as for new parts, except that repair limits would be

established by the constructors, and it would be unwise to vary them unless considerable experience had been accumulated by the ground engineer.

Screw Gauges

Threaded work entails the use of sundry gauges to control the various elements within the tolerances laid down by the British Standards Institution.

The elements of a thread include: full diameter, effective diameter, core diameter, pitch and angle. All these factors, except angle, can be maintained within the desired tolerances by the provision of "go" and "not go" ring and plug gauges. Hitherto the use of ring gauges has been prevalent, but this system is being superseded by the open type caliper gauge. The "Wickman" is a sample of this later development.

Ring gauges cannot adequately control all the elements of a thread, but the "Wickman" type gauge, which is, in effect, two gauges in one, and is provided with two sets of anvils, controls the dimensions of a screw thread in a similar manner to that of a normal gap gauge. The upper set is similar in form to an external chaser, has threads of full form, and is the "go" portion of the gauge, the lower set is restricted to a few truncated threads which, in practice, forms the "not go" portion of the gauge.

The main advantage of this type of gauge is the fact that pitch, angle, and form are taken care of by the full form anvils, and the effective diameter, which is of prime importance, is controlled by the lower set of anvils. It must be borne in mind that male work only can be checked, and this must be applied in a downward direction on the anvil faces.

The screw plug gauges are still retained for checking female screwed work, the full form "go" plug for general form and pitch, the effective "not go" plug for effective diameter, and the core "go" and "not go" plug for the core or root diameter.

To adequately check any work to the drawing tolerance, "go" and "not go" gauges must be used and sensibly applied, and it must be remembered that force in applying the gauges to the work is not permissible.

It will be observed from the B.S.I. Reports that with a nut on maximum dimension and a bolt on minimum dimension a fair amount of slackness will be obtained. There is always a ·002 in. tolerance between maximum bolt and minimum nut on all but B.A. threads.

Work which requires a smaller tolerance can be made to "close fits," the tolerances in this case being half the normal. Such fits are desirable on master rod bolts and nuts, etc.

There is a method of checking the effective diameter of male screw threads in which calibrated ground needles, or wires, of known diameter are used. A wire is placed in the "vee" on each side of the thread, and the diameter over the wires measured with a micrometer. From this dimension the effective diameter can be determined.

The same method can be used to measure serrated shafts and

similar parts, but care must be taken to remove burrs or sharp edges from the teeth before fitting the wires.

Needles or wires are selected so that they make contact about half way down the flank of the thread.

The Zeiss micrometer, of which an example is illustrated on Plate X, incorporates this principle, but the usual methods of suspending the wires or using magnetized wires, which are not entirely satisfactory, have

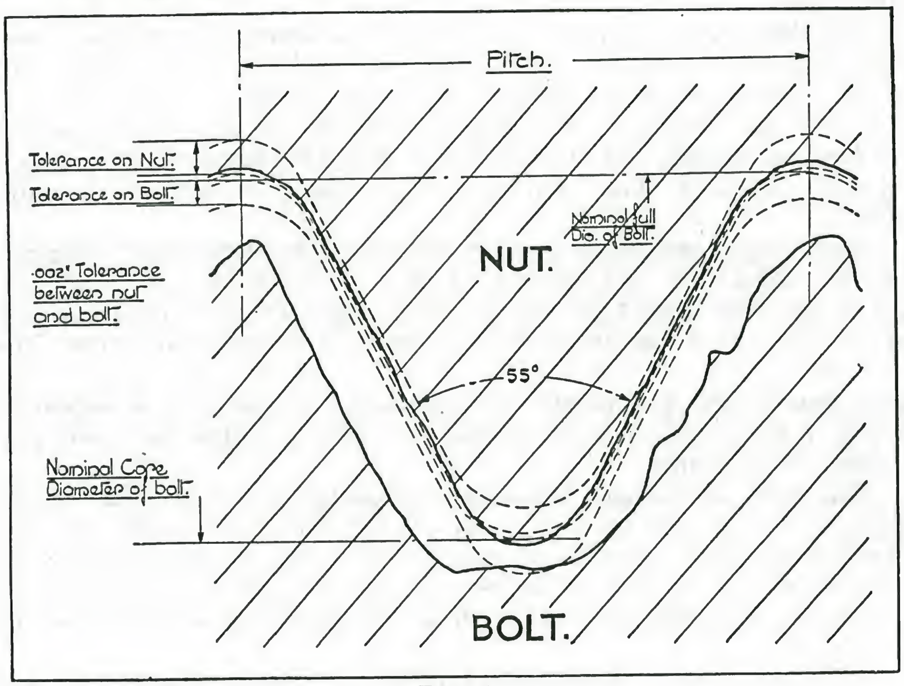


FIG. 5

been altered to overcome these disadvantages, the wires being mounted so that they can easily be fitted to the anvils of a micrometer.

For medium-size threads the three wires are mounted in two frames carried on the micrometer anvils.

For measuring coarse pitch threads the pair of wires in the frame is backed by a gauge block which makes contact with the micrometer anvil.

The three wires are held loosely in the two frames so that they will adapt themselves in a position in the thread. The wires in a set are of uniform size, are interchangeable, and may be re-ordered individually at any time.

Rapidity in operation is greatly increased because no calculations are necessary. Tables are supplied for each thread standard, giving the diameter of thread, threads per inch, wire diameter and the reading which the micrometer should register. Any deviation from this latter figure indicates an error either plus or minus in the effective diameter of the thread. Readings can be estimated to the fourth decimal place.

PROJECTION. A convenient method of checking thread forms is to project the magnified profile of the thread on to a screen on which a line diagram of a true thread form is drawn.

Fig. 5 shows such a diagram with the images of bolt and nut threads superimposed on it.

The specimen is set up and the image adjusted to its correct height. If the thread has been properly formed the whole of the image should fall within the two lines representing the permissible tolerance.

In the case of female threads, a plaster impression is made for the purpose of projection.

It will be noticed in the diagram that the thread of the bolt is very rough and incorrect on the crest and effective diameter.

The thread of the nut is fairly good, except for the crest diameter.

One or two manufacturers favour the truncated thread in which the crest is removed. This ensures that a nut and bolt are definitely in engagement on the effective diameter of the threads. In the case of stainless steel parts, the truncated thread reduces the tendency to drag when using the tap or the die.

Inspection Prior to Overhaul

We now come to inspection prior to the overhaul of an engine, and it should be clear that new or subsequent engines will have been built exactly like the type engine, except that subsequent approved modifications may have been incorporated on later engines. In the same way when overhauling an engine, it is important to maintain a close liaison with the constructors, in order that advantage may be taken of their endeavours to improve the functioning of an engine by the incorporation of any modifications that have been approved. In addition, any modification affecting safety would be promulgated in the form of a Notice to Aircraft Owners and Ground Engineers, and it is a definite duty of the ground engineer to incorporate such modifications, as indicated in the notice, otherwise he would be wrong in certifying a log book on completion of the overhaul.

Notices to Aircraft Owners and Ground Engineers are not issued to a person until he actually holds a licence, although a book embracing all Notices from 1920 to 1937 inclusive may be obtained from H.M. Stationery Office (price 2s. 6d.). All subsequent Notices up to the time of applying for a licence are held by qualified ground engineers, and by consulting them the candidate is able to become familiar with all notices relating to a particular engine.

When an engine is received for repair or overhaul it is advisable carefully to peruse the log book to ascertain the condition and period of running.

It is becoming the usual practice to include as running time only such running as occurs in the air, ignoring ground running, and including ground tests as log entries but not as a part of the period of running between top or complete overhauls.

The engine should be stripped down stage by stage, each part being carefully examined in the oily condition. By this means the ground engineer can get a good idea as to whether the running during operation in the aircraft has been satisfactory.

Excessive overheating, detonation, etc., in an engine might be evidenced by the condition of the cylinder heads, piston crowns, valve

seatings and valves, as also the nature of the carbon on the piston crowns. (See Plates XII and XIII.)

Sand and other foreign matter entering the air intakes cause excessive wear of piston rings, valve guides, valve seatings, bearings and ridging at the top of the cylinder bores. Crankpins and connecting rod bearings may show less distress than the crankshaft journal bearings if the lubricating oil is dirty, owing to the centrifuging effect of the crankpins and reciprocating effect of the connecting rods.

The extent and nature of the sludge in crankpins and oil holes of pistons, etc., and the freedom of rings on the pistons would provide evidence of the suitability of the lubricating oil, under the particular conditions the engine was operating.

Excessive sludging may be due to oxidization of the oil which would produce small amounts of asphaltic substances.

It should be appreciated that oil draining from the underside of pistons may be at temperatures of from 200° C. to 250° C., and this crankcase oil may become oxidized through contact with the exhaust gases that get past badly fitting piston rings. Oils subjected to oxidization may become corrosive and dirty oil is conducive to the wear of parts, heat flow is reduced and carbon is formed. For the above reasons oil should be changed at regular intervals as recommended by the makers of the engine, or earlier if indicated by the condition of the filters.

The residue or sludge in the crankcase filter requires particular attention so that in the event of metallic particles being found therein the cause can be ascertained as the strip of the engine proceeds.

The oil drawn off from the filter chamber when the filter is removed, should be allowed to settle and subsequently poured away, leaving only the residue remaining. This should be thoroughly washed with petrol several times until all the oil has been removed. The filter should be thoroughly washed and cleaned and the residue added to that already collected. Black particles will give some indication of the extent of carbon formation. If brass or lead bronze particles are present they can normally be identified by their yellow colour. Steel and iron are magnetic and if present would be attracted to a magnetized body. It is more difficult to differentiate between aluminium and white-metal if either is present, but aluminium will be readily attacked by a 10 per cent solution of caustic soda in water. If there is no reaction, white-metal only can be assumed to be present. As a general statement, metal from main bearings appears as thin flakes or if breaking up badly, small irregular crystals. Metal from bushes which have partially seized will be present in the form of dust.

A further examination of parts would show whether the engine generally had been adequately lubricated, and whether oil ways were clear.

Vibration, both local and general, would almost certainly reflect worrying on the parts concerned.

The next stage will be the cleaning of all parts, followed by a careful and detailed inspection and measure up of all wearing parts. The preparation of a detailed report on the work to be carried out is essential.

It is desired to stress the importance of keeping the paraffin washing tanks scrupulously clean, and free from sand and dirt. The paraffin should be periodically filtered and changed. Care should be taken when removing carbon from the various parts to see that no coarse emery cloth is used, as the risk of leaving marks which might be the start of subsequent failure must not be overlooked. Do not use cotton waste for cleaning purposes, as it catches on threaded parts and is liable to get into an engine, if not noticed on assembly. Protect all studs with their own nuts as soon as they have been cleaned, dried, and lubricated.

Inspection During Overhaul

Inspection should be directed to eliminate any parts in which defects have started to develop, or excessive wear is evident which might lead to failure prior to the next overhaul. With established types of engines, performance and other data may be available which would enable discretion to be exercised in the acceptance of parts with minor defects, but as it is the practice to extend the period between overhauls from time to time, this point must not be overlooked. A part might be considered serviceable on a new type of engine with an anticipated life between overhauls of, say, 200 hours, but might be rejected on a well-established engine scheduled to run, say, 400 hours between overhauls.

The constructors of a particular engine usually provide a schedule of clearances based on long experience of the type. This schedule should indicate the "permissible worn dimensions" and the "permissible worn clearances" of the various parts. The former represent the limit of size to which parts may be worn, and re-fitted for a further period of service, whilst the latter is the limit of working clearances permissible between any two parts assembled together.

It will be realized then that to accommodate this latter condition it may be necessary selectively to assemble parts, that is to say, a part worn near the bottom limit may have to be assembled with a mating part that is closer to its nominal dimension.

The ground engineer should possess a list of clearances for all important parts, and whilst it is unnecessary for him to commit them to memory, he is expected to show an intelligent knowledge of them, particularly where the dimension is critical, such as, for example, the diametral clearance and float of the crankpin bush or bearing shell.

The ground engineer is at liberty to use his discretion in extending these limits, but it would be an unwise course to take unless he had had very exceptional experience of the particular type of engine. Certain operating companies, properly equipped to undertake the complete overhaul and test of their engines, are, however, in this position owing to the accumulated experience of a particular type of engine, but even then a close co-operation is usually maintained with the constructors.

The inspection of parts normally falls into three categories: serviceable, repairable, and scrap. The last one includes parts scrapped for condition, those rendered obsolete as a result of modification or a Notice to Aircraft Owners and Ground Engineers, and parts such as

valves, pistons, etc., which are given a limited "life" by some manufacturers, regardless of condition. It is always good practice to mark parts with red paint, adjacent to a defect, so that they cannot be reassembled without rectification.

Split-pins and tab-washers should be soft, and can be annealed by heating to a cherry red if there is any doubt.

Split-pins are never used twice, neither are tab-washers unless they are in good condition and one unused tab still remains. Circlips can often be rendered scrap by overstressing if suitable tweezers are not available, and other methods are resorted to.

Jointing material, rubber and cork packings, etc., very often have to be scrapped owing to condition or prior use. When an engine has been removed from a crashed aircraft all parts must necessarily be under suspicion, and any showing damage or distortion are normally scrapped.

It is important that all scrap is defaced so that it is impossible inadvertently to use it again.

It is now proposed to mention some of the more important points during inspection of the various components prior to rectification and overhaul.

Crankcases. A careful examination for cracks in the flanges, stiffening webs, and bearer feet is required, and whilst experience only can decide the seriousness of each crack, it is known that with certain types of engine, cracks in certain places are not unusual, and do not normally develop, and a certain amount of discretion would be permitted in accepting parts, providing the defects were constantly under observation during routine inspections.

All studs should be checked for tightness, and in cases where a loose stud is found a new one, selected with the thread on the top limit, or, alternatively, a stud ·002 in. oversize, may be fitted. If there is plenty of metal around the stud hole a satisfactory job can be made by bushing the original hole to accommodate a standard stud. The bush should be screwed in tightly and locked by a grub screw.

When broken studs have to be dealt with either on a steel or aluminium part, it is often possible to remove them, without damaging the thread in the part, by drilling, using a drill just smaller than the root diameter of the stud. A carefully applied standard tap will then usually remove the remaining metal threads.

All face joints should be examined for damage and flatness and old jointing material carefully cleaned off.

All oil-ways should be syringed to see that there are no obstructions.

Bearing housings should be examined, and whilst indications of a creeping race will occasionally be found, this is not detrimental providing the bearing is a reasonably tight fit when reassembled. Slackness results in hammering under running conditions with a risk of collapse of the housing, and must be dealt with by fitting an oversize bearing. Care must be taken when machining out the housing to use jigs similar to those used by the constructors, in order that the original centres may be maintained. This point becomes particularly important in the

case of reduction gears, where it is essential that the tooth clearances are maintained within drawing requirements.

Many designs of crankcase incorporate detachable steel housings in which the ball or roller race is fitted; in these cases the housing can be renewed and a standard race retained.

With rotary engines, when steel crankcases are normally employed, the housing, if worn, can be restored by metal deposition.

Crankshafts. The first point to check is "bowing." This is done by mounting the crankshaft on "vee" blocks, and checking the bearings with a dial indicator whilst the part is being rotated.

Inline crankshafts should be supported at positions about a quarter and three-quarters along their length to compensate for any sag, and thus eliminate any error due to their weight. Any journals which are clocked should be smooth and true. Crankpins should be checked for parallelism with the axis of the shaft, and all journals and crankpins for ovality and condition.

In the case of crankshafts of radial and rotary engines, many of which are of the built-up type, it is necessary to make a careful check at the extremities of the shaft when it is mounted on its main bearings supported on "vee" blocks.

If the crankshaft is removed from a crashed engine, or if marks or defects are present which might originate the start of a fatigue crack, a check should be made by immersing the crankshaft in oil at a temperature of 200° C., drying off the surface oil with a cloth, and then sprinkling chalk over it. As the crankshaft cools down, oil will exude as a fine line on the chalk if a crack is present. The test becomes more searching if the webs of the crankshaft are hit with a hide hammer. Another method is to etch the shaft, using a solution of 5 per cent nitric acid in methylated spirits. The etching continues until the shaft has become dull grey, when it is washed in a solution of common soda dissolved in water. After the shaft has been allowed to remain for a period of 10 to 15 minutes it should be examined with a 10 : 1 magnifying glass to ascertain whether there is a crack.

The part should be subsequently tempered at from 100 to 200° C. to remove any tendency to brittleness.

Stressed steel parts, as also those with case-hardened surfaces, are normally tested for the presence of cracks with a magnetic crack detector. The principle upon which it operates is as follows—

If a magnetic flux is passed through the steel part to be tested and a crack is present in the flux path, magnetic poles will be formed on each side of the crack.

The part to be tested should be put in various positions, in a fairly strong magnetic field. It should then be immersed in paraffin having soft iron dust in suspension, or alternatively, the liquid may be poured over it. Iron dust will be found to adhere along the edge of a crack, if present, but will give no reaction if the mark is in effect surface damage only. The paraffin should be stirred prior to use.

The part, if serviceable, should be finally demagnetized by passing it through an alternating current field, in order to prevent particles of metal in the oil adhering, when the part is assembled in an engine.

This process will confirm a suspected crack and show up others that might be missed by visual inspection.

The following additional precautions may be mentioned—

(i) Parts must be free of grease, oil, and carbon.

(ii) An aluminium ladle should be used for pouring the paraffin over the parts.

(iii) The test should be repeated if doubt exists as to the presence of a crack.

(iv) A compass will be useful to ensure that parts are demagnetized.

(v) Austenitic steels cannot be checked by this process as they are non-magnetic.

(vi) Cadmium-plated parts must have the plating removed prior to applying the test. Bright drawn bar can also be tested.

The Electra flux test is also made for crack detection. In this test a heavy low voltage alternating current is passed through the part and no demagnetizing is required afterwards. Cracks running in the direction of the current flow are indicated.

A crankshaft should not require re-balancing unless the balance weights are changed. Main bearing housings should be examined for condition and wear. The inner races of ball and roller bearings are either driven on with the assistance of tallow as a lubricant, or shrunk on to the crankshaft, the latter method comprising pre-heating the race in hot oil. In either case the fit is important, and if it cannot be obtained by selecting a bearing, the crankshaft housing would have to be metal-deposited in an approved manner. Nickel or iron depositions are satisfactory for this purpose. (See Plate XIVA.)

It is undesirable to renew individual rollers of roller races unless the workshop is equipped with suitable apparatus that is capable of measuring to ·0001 in.

The serrations on airscrew shafts should be carefully examined and the hub should be a push fit on the shaft without any appreciable slackness. The cones for the airscrew hubs on other engines should be examined, and any slight degree of picking up eased; the hub should then be lightly lapped on to its shaft, using a fine abrasive.

After thoroughly cleaning the inside taper of hub and the cone on the shaft, the hub should again be offered up to the shaft for correctness of fit. The bore of the hub should be sparingly coated with Prussian Blue, lightly pressed home on the shaft and turned in position. On withdrawing the hub it is essential that it shall show a good marking on the shaft.

When assembling the hub, check must be made to ensure the correct fitting of key which must have top clearance but no side clearance. This can be verified by placing a piece of thin lead wire on top of the key.

To ensure that the hub draws up satisfactorily on the shaft, the taper should be covered with a coating of thin oil, which is then wiped off so as to leave only an oily surface insufficient to interfere with metal to metal contact. Some hubs have a slight difference in taper relative to the shaft. In such cases the hub must not be lapped onto its shaft, as the difference in taper referred to above ensures a tight fit on the rear of the taper which must not be interfered with.

CYLINDERS. Pressure tests, already indicated, would reveal leaky seatings, adaptors, and faulty cylinder head joints in those designs where the barrel is screwed into the head. Such parts could only be rectified by the constructors, who are equipped with suitable apparatus, and even then there is risk of scrapping some of the parts. With multiple cylinder head construction, appropriate pressures would be given both to the headers and the water jackets, with a view to revealing cracks, porosity or leaky joints. Suitable expanding rubber joints would be utilized for the tests to block up the various orifices. Water jackets are prone to build up deposits of lime after long periods of engine running, and they can be a source of danger, from the point of view of overheating if they are not removed. A 25 per cent solution of Clensol in hot water, circulated around the water jacket for a number of hours, will normally remove the bulk of the deposit. This treatment should be followed by a period of washing with clean water. The nature of the deposit is largely dependent on the source of supply of the water, which may contain salts of magnesium, calcium, sodium, and in some cases iron.

Valve seatings should be examined for tightness, pocketing, pitting, etc., and may be re-cut if the dimensions permit. The practice of fitting N.C.M. steel seatings in cylinder heads of air-cooled engines is now becoming general because of the reduced tendency of the valves to pick up, the superior resistance to leaded fuels, and the greater resistance to shock loadings at elevated temperatures. With seatings in this material, the spring loaded hand-operated tools for recutting the seatings is ineffective, particularly if a cylinder has had considerable service and the seating is scaled. In these cases it is usual to grind the seatings to restore their surfaces, using specially designed power-driven tools such as the Black and Decker, Hall, etc., but care is required to see that the minimum of material is removed in order to get the maximum life out of the part. The equipment includes a fixture, incorporating a diamond, for periodically trimming and dressing the various roughing and finishing grinding wheels. These will probably comprise a set of three or more wheels for each valve seating. It is important that the valve guides have smooth bores within drawing limits as the apparatus is located from them and any errors present would be reproduced. It is usual, when the grinding is completed, to lightly bed each valve on to its seating, using a very fine abrasive, finally checking with Prussian blue in the usual way.

In some engines the angle of the seat of the exhaust valve is 1 degree different from that of the seating. It is claimed that when the valve is at working temperature a maximum seat contact is obtained. In these cases bedding the valve on its seating cannot be done, but it is usual to employ a standard angle valve for this purpose. Slight movement of seatings is the forerunner of loose seatings, and a good indication can be obtained by examining the part after careful cleaning. If the seating and head joint is defined by an apparent line, it is advisable to treat the cylinder with suspicion and subject it to a water-pressure test at 400 to 600 lb. per sq. in.

Some engine builders mark the seatings in such a way that movement

can readily be detected on examination. One manufacturer, for example, provides three centre pop marks in line, the centre one being on the cylinder head, whilst the other two are on the adjacent portion of the inlet and exhaust valve seating respectively.

When cracked seatings occur it may be generally assumed that if the material is sound and in the correct condition, the cause of failure is initial overtightening, probably as the result of the use of an incorrect tool permitting too much strain to be imposed.

If engines are permitted to be run with excessive valve clearances, the rebound of the valve on the seating may easily result in abnormal wear and possibly breakage of the valve under the tulip.

Cylinder bores should be checked for ovality at two axes at right angles to each other, both at the top and bottom positions of the piston travel. Cylinder wear is most apparent near the combustion head and the step formed corresponds to the limit of travel of the top gas ring. If this ring has been gummed up for a lengthy period of engine running a second step will make its appearance corresponding to the limit of travel of the second ring. In both cases the positions correspond to the limit of the oil film and the position of greatest heat, producing dry momentary scoring as the oil film is penetrated.

Cylinder wear is normally greater with supercharged engines, owing to the higher temperatures and piston ring pressures. Excessive wear will also result from contamination of the induction air due to sand, etc., and to some extent by the products of combustion.

In starting up an engine the risk of underlubrication is great until oil is splashed up in adequate quantities.

With certain designs of cylinder construction, where the barrel protrudes unsupported for some distance into the crankcase, it may be permissible to extend the limit of ovality at the mouth beyond that established for other positions.

Cylinders would normally be rejected if any blueing was noted in the bores, and would require rectification if any picking up or scoring were indicated. Excessive scoring would entail re-grinding the bore if the dimensions permitted. Re-grinding of air-cooled cylinders will only produce true round bores when the correct equipment is used and there are no soft patches in the metal. The finning in conjunction with thin walls tends to make the grinding wheel cut locally, and glaze in between the fin areas unless every care is taken.

Honing, for which a definition is given in Appendix II, is sometimes done to improve the finish of the bore of a cylinder that has been re-ground, but it is absolutely essential to thoroughly wash out the cylinder in order to remove every trace of abrasive which is used and sludge which is formed during the process. Moderate scoring could be rectified by careful lapping with a dummy piston, using a very mild abrasive, such as Turkey powder made into a thin paste with castor oil, followed by crocus powder (rouge) and oil. For very mild forms of scoring the crocus powder and oil would be suitable.

Inspection of cylinder bores should be done in a good light, and is facilitated by the use of a polished aluminium disc with a rod passing through the centre. This can be used to reflect the light to any part of

the bore. Failing this piece of inexpensive apparatus a piece of white paper placed at the bottom of the cylinder would be of assistance.

VALVES. The power output of modern aero engines has increased, due largely to higher crankshaft speeds and compression ratios. In addition, boosting up to 8 lb./sq. in. is allowed on some engines. Cylinder temperatures, during engine running, have increased, particularly with liquid cooled engines using coolants permitting temperatures well above those possible with water cooling.

Exhaust valves are consequently expected to function at temperatures between 700/900° C., whilst the exhaust gases are over 1000° C. Particular provision is therefore required to carry away the excess heat from the valve heads. One method of effecting the transfer of heat from the head to the stem and thence to the valve guide, is by using a hollow stem valve two-thirds full of metallic sodium. This metal has a melting point of 97° C. and a boiling point of 883° C. It will be seen then, that whilst an engine is running, the sodium will be in liquid form and heat will be transferred by agitation.

The contact of the liquid metal with the wall of the valve stem is better than with other molten salts and the heat transfer is more effective provided the thermal conductivity of the valve guide is satisfactory.

It is known that a valve is liable to develop surface cracks as the result of hardening due to prolonged periods of running at elevated temperatures.

It is probable that gas leakage precedes pitting and burning of the seats, these conditions being accelerated by prolonged running on weak mixtures, or valve stretch causing insufficient clearance which prevents the valve from properly closing. Leaded fuel attacks the heads of valves and stellite or Brightray coatings are provided to retard corrosion. Penetration is less on end grain than along the grain of steel and valve stampings are up-ended and subsequently forged to obtain the former condition on the seats.

The stems are sometimes nitrided in order to reduce any tendency to picking up in their guides and to procure the maximum thermal conductivity.

Exhaust valve failures occur under the tulip, due to intercrystalline corrosion; fatigue resulting, amongst other things, from excessive exhaust gas temperatures.

Prior to actual failure of a valve, circumferential cracks may be noted at a point where the stem blends into the radius of the head, although actually they will occur near or at the region of maximum temperature.

Pitting may also be noted around the stem in the same locality.

Some makers limit the life of valves as a precautionary measure.

For these reasons valves should be examined minutely, after discriminate cleaning, for stretch, cracks on the seats and stems, distorted heads, bent stems, etc.

Fig. 6 shows two gauges which could easily be made and which would prove invaluable in this connection. They include a gauge for checking stretch, and a flat contour gauge. Worn or loose valve

guides can, of course, be replaced by oversize ones, and where fitted, it is necessary to ream them out and possibly re-cut the valve seatings.

It is undesirable to depart from the makers' recommended procedure for the fitting of valve guides, and in this connection it is not usual to use any lubricant as, otherwise, the thermal conductivity is impaired. In other cases it is the normal practice to pre-heat the header before renewing the guide. Valve springs should be examined for

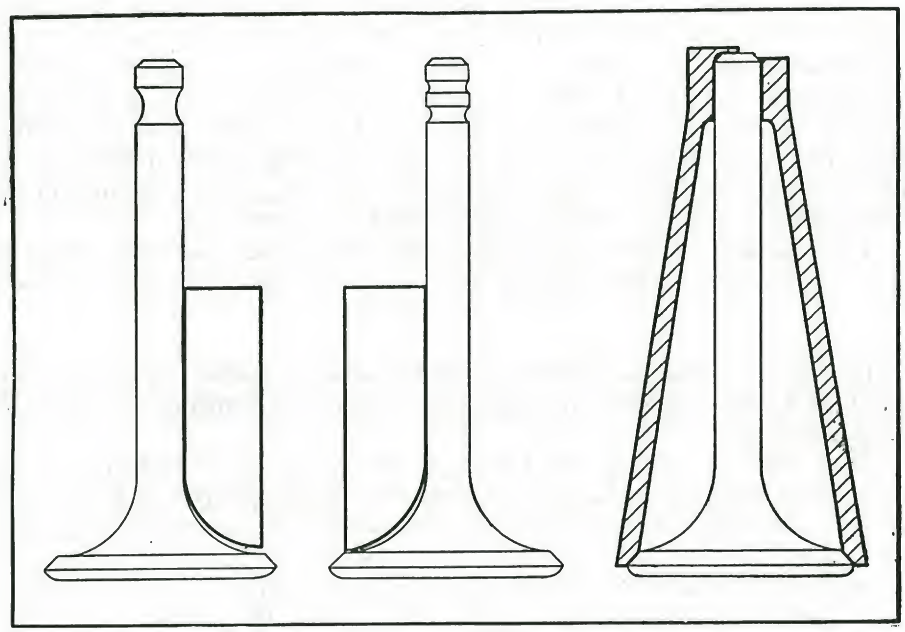


FIG. 6. GAUGES FOR CHECKING VALVE STRETCH AND CONTOURS

surface defects, die-marks and surface erosion. Bent springs and those not sitting squarely on their locations or retaining washers are liable to fail and will in all probability impose a side load on the valve stem and incur valve guide wear.

Some makers manufacture springs which are only flat when under load. Valve rocker pads, if worn, should normally be renewed, although in certain cases stoning up is possible. Worn ball ends should be scrapped without any attempt at rectification.

CONNECTING RODS. These should be checked in exactly the same way as new parts. Cold setting, to correct any errors of alignment, is not permissible, as this might set up local hardening, and start a fatigue crack at a later date. Particular attention should be directed to cracks around bolt holes, lightening holes, radii, etc. All studs and bolts should be carefully checked for stretching, as the result of initial over-tightening, or deterioration due to hammer loads associated with slack clearances during engine running. Oil pipes and passages should be syringed, and any soldered or brazed joints made good if leakage is noted. Wrist pin and gudgeon pin bores should be carefully checked

for ovality and wear with a suitable plug gauge, having flats on it in such a way that only one axis is operative. A slack bush tends to elongate rather than wear the eye of the rod, and if not dealt with in time, might result in failure. If re-grinding the bores of a rod is permissible, this should be done on a suitable fixture in order to maintain the correct distance between the centres of the bores for the gudgeon pin and wrist pin. On the same kind of fixture a re-metalled connecting rod must have the bearing metal machined to a diameter corresponding to its appropriate pin on the crankshaft, allowance being made, of course, for the initial diametral clearance after bedding the bearing.

There is a growing tendency to fix the bushes in connecting rods, and inspection should be made to ensure that the locking screws, pegs, or dowels are secure. When changing bushes the makers' procedure should be followed, and the interference fit laid down should be maintained.

Bearings. It is usual to reject any parts where the white-metal shows the slightest crack or lack of adhesion, and no filling or soldering is permitted under any condition. Cracks develop as the result of shearing stresses set up in the white-metal at points of high pressure, but by discriminate relieving with a scraper the load is distributed over a larger area of the bearing. This slight easing of the metal in the early stages may prevent the subsequent development of cracks. Certain designs of connecting rod are known to be more flexible than others and disintegration of the bearing metal from the shell or rod as the case may be must inevitably occur under running conditions, and cracks will eventually form over part or the whole of the bearing surface, but will not of necessity develop sufficiently before the normal overhaul period is expired to warrant replacement if left undisturbed. Provided the disintegration does not extend to the radiused edges of the bearing, the oil seal is unlikely to be impaired.

To minimize the effects of distortion it is not unusual to provide local reliefs.

If a bearing has been running with a temporary shortage of oil, it has probably been sufficiently warm to wipe the surface of the white-metal. If a slight seizure has occurred oil-holes may be partially blocked with white-metal in addition to very definite evidence of wiping. In the former case rectification might be effected by careful burnishing and the removal of high spots.

When connecting rod bearings are lined with lead bronze, additional precautions are required to those already mentioned, and it may be assumed that the following remarks apply generally to all lead bronze bearings for aero-engines.

When once a new bearing has been properly fitted and adequately run in, a hard glazed surface is obtained, which stands up better to high loads, speeds, and temperatures than white-metal. The initial surfacing of the bearing can be obtained by prolonged engine running at progressively increasing speeds, or by preliminary running on a rig in conjunction with the discriminate use of dressings. High spots should be removed by scraping as in the case of white-metal. The diametrical

clearances are critical and the figures laid down by the manufacturers must be adhered to. The clearances can be checked either by the insertion of a strip of copper foil around the crankpin or by the use of an oversized mandrel.

The Solex pneumatic micrometer is used in the aircraft industry for various classes of precision measurement, that of the bores being perhaps its most general application.

The apparatus consists of—

(i) A pressure controller for air supplied from the mains.

(ii) A column of liquid, with a scale, graduated either in Metric or English measure, on which dimensional variations of the part being measured, are indicated.

(iii) A flexible pipe conveying air to the gauge.

(iv) The gauge.

The height of liquid is a measure of the pressure variation resulting from leakage of air between one or more nozzles incorporated in the gauge and the surface of the bore under-measurement.

A typical male gauge is shown diagramatically in Plate XA and the system is practicable with gauges as small as 5 mm. diameter.

It will be noted that there are two apertures directly opposite to each other. The air leak and consequently pressure variation will occur in direct proportion to the clearance between the apertures and the bore. If the bore is exactly nominal size, the scale reading will indicate zero.

It will be seen that the gauge can be used to explore a bore at any position for ovality, taper and plus or minus errors and 0·0001 in. variation will be indicated by movement of the liquid column of approximately 0·5 in.

The following other applications of this apparatus, for aero engines, are made—

(i) Calibration of small apertures and flows.

(ii) Measurement of journal bearing bores.

(iii) Sealing capacity of valves such as float chamber needle valves.

A certain amount of porosity, as exhibited by pin holes, may be expected but it is not considered to be detrimental. A lead bronze bearing, after a period of running, may show the presence of lead in patches or irregular lines on the surface of the bearing. This is not unusual but must not be confused with wiping associated with oil shortage. If a bearing starts to disintegrate it is usual for the detached pieces to remain in position if the edges of the bearing are intact. Further, it is generally recognized that lead bronze bearings function better with high oil pressure and low oil temperatures.

Pistons. An examination should be made for cracks, particularly in webs and bosses. Any scoring on the skirt should be rectified by polishing or discriminate burnishing. Any signs of burning should automatically reject the part. The piston ring and circlip grooves should be examined for hammering and wear. Pistons of modern aero-engines are manufactured from heat-treated aluminium alloy forgings, and the effect of prolonged engine running may have an annealing

effect resulting in a considerable drop in Brinell hardness on the top lands and crown. Provided that this drop is reasonably uniform on all pistons, it may be considered a normal feature. If pistons are roughly handled, there is every risk of the skirts springing out of round.

Gas and scraper rings should be examined for blowing, loading, and general condition.

It is undesirable to remove piston and scraper rings from pistons

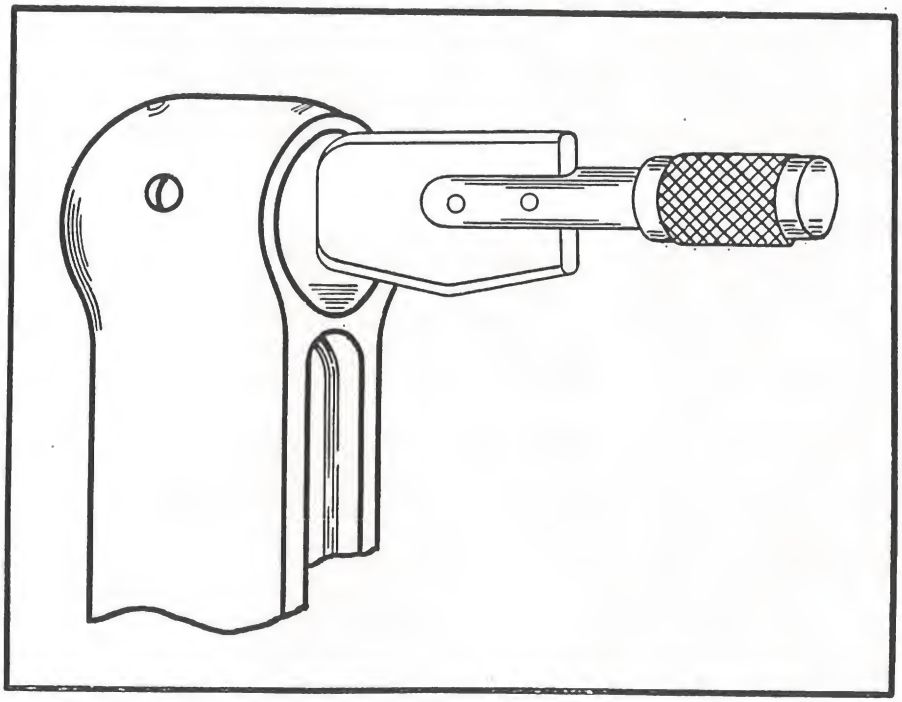


FIG. 7. FLAT GAUGE FOR CHECKING OVALITY OF BORES

unless they are found to be defective or gummed up. If it is necessary, then every care should be exercised to prevent stressing and distortion. A safe procedure is to insert two $\frac{1}{4}$ in. wide steel strips behind the ring at a position opposite to the gap, then move them apart radially round the piston. Insert a third strip as before and then continue to move the first two strips round until the ends of the ring are free of the groove. The ring should then be moved up the strips until clear of the piston. Each ring should be removed in a like manner. Old hack-saw blades with teeth ground off can be used in place of strips. (See Plate XI.)

Inspection should be made for "toeing in," feathering, scoring of rubbing surfaces, signs of gas blowing, etc. Any of these defects should normally warrant rejection of the part because rings are cheap. On the other hand, if defective rings are used, the results may be expensive in the long run. A careful check of gaps should be made because ring tension diminishes slightly each time it is heated up, although heat formed rings may behave better in this respect. Rings with excessive gaps, when fitted in the cylinder, may permit hot gases to pass which would in all probability cause local heating of the rings, and if gases can pass

behind them this is even more serious. It should be remembered that every ·001 in. rubbed off the surface of a ring increases the gap about three times that amount.

Case-hardening parts, such as cams, gudgeon pins, gears, etc., are carefully examined for wear and chipping or flaking of the case. Wear and chipping can often be dealt with by careful dressing with a stone, but flaking will probably warrant the rejection of the part. Extensive blueing would normally entail the rejection of a part.

Cracks are prone to develop, particularly at the roots of teeth, as the result of shock loadings, under engine running conditions, and minute cooling or grinding cracks sometimes show up on parts such as wrist pins, so inspection should be directed to search for this class of defect.

Accessories

Under this heading we shall include magnetos, carburettors, oil, air, petrol, and water pumps, compressors, and sparking plugs.

With the exception of magnetos, they should all normally be stripped right down, inspected for wear and mechanical damage, and after re-assembly be subjected to suitable functioning tests apart from those on the engine.

MAGNETOS. These should not be completely dismantled. This work can only be undertaken by a ground engineer holding an "X" licence, a firm approved for magneto overhauls, or the manufacturers.

A number of minor adjustments may, however, be made, and the following details are mentioned for guidance.

If a contact breaker arm is sticking, it may be removed, cleaned, and re-assembled with the recommended lubricant. Contact points should be cleaned, adjusted, and, if necessary, changed. Erratic running may result if they are not given proper attention. Contact breaker springs may be renewed. If the straw-coloured springs show signs of discoloration, due to the action of ozone, etc., this may be taken as an early indication of pending failure, and such springs should be changed.

If the fibre heel on the rocker arm is burnt or worn, it is probable that the cam oil pad has not been regularly lubricated.

It is undesirable to wash contact breakers in petrol, as the burning of platinum points is accelerated if petrol vapour is present.

It is quite permissible to renew carbon brushes after thoroughly cleaning the tracks.

Distributors should be carefully examined for cracks in the moulding, but should not be changed.

Metal screens, lubricators, rusty or damaged external screws, etc., may be changed.

The impulse starter, if fitted, may be dismantled and cleaned.

The following brief description of an impulse starter fitted on B.T.H. magnetos may be instructive and Plate XVIII shows one of these starters dismantled.

The device consists essentially of three parts, the driving member

(*F*) which is coupled to the engine shaft driving the magneto, hub assembly (*D*) which is rigidly secured to the magneto spindle, and the end plate (*B*) which is secured by screws to the magneto casing.

The driving member and hub assembly are linked together with a stout clock type spring (*H*). The hub carries two weighted pawls (*E*), the ends opposite the balance weights (*L*) of which engage with the cam profile machined on the inside face of the driving member.

The endplate is provided with two stops (*A*).

The action of the impulse starter is as follows—

(i) When the driving member is rotated, one of the pawls will reach the top position and being free to drop, the rib on the underside of the balance weight engages with one of the stops on the endplate. The armature of the magneto and hub assembly are thus temporarily locked together.

(ii) Further rotation of the driving member will cause the spring to be wound up, and an angular displacement will take place between the driving member and hub assembly. The displacement is controlled by stops *I* which only permit movement within the annular grooves *C* and also provide a safeguard in the event of the spring breaking.

(iii) At a predetermined position the cam (*J*) on the inside face of the driving member, engages with the pawl (*E*) and forces it inward.

(iv) This disengages the pawl from the stop in the endplate and due to the previous winding up of the spring the hub assembly together with the armature is released, thus receiving a sudden impulse. The magneto is timed so that the contact breaker points separate during this very rapid "flick over" and an intense spark is thus automatically produced.

(v) The pawls are so weighted that the heavy ends are thrown outwards by centrifugal force and automatically clear themselves from further engagement with the stop (*A*) on the endplate as soon as the engine accelerates.

(vi) As soon as the pawls are disengaged, the driving member and hub assembly rotate as a single unit.

Carburettors. The inspection of the parts will include—

(i) A careful check of needle valves, throttles, and other moving parts for freedom of movement.

(ii) All pins and toggles must be examined for wear and consequent slackness.

(iii) Floats must be tested for leakage, and cork floats should be specially examined for deterioration of the protective dope coating.

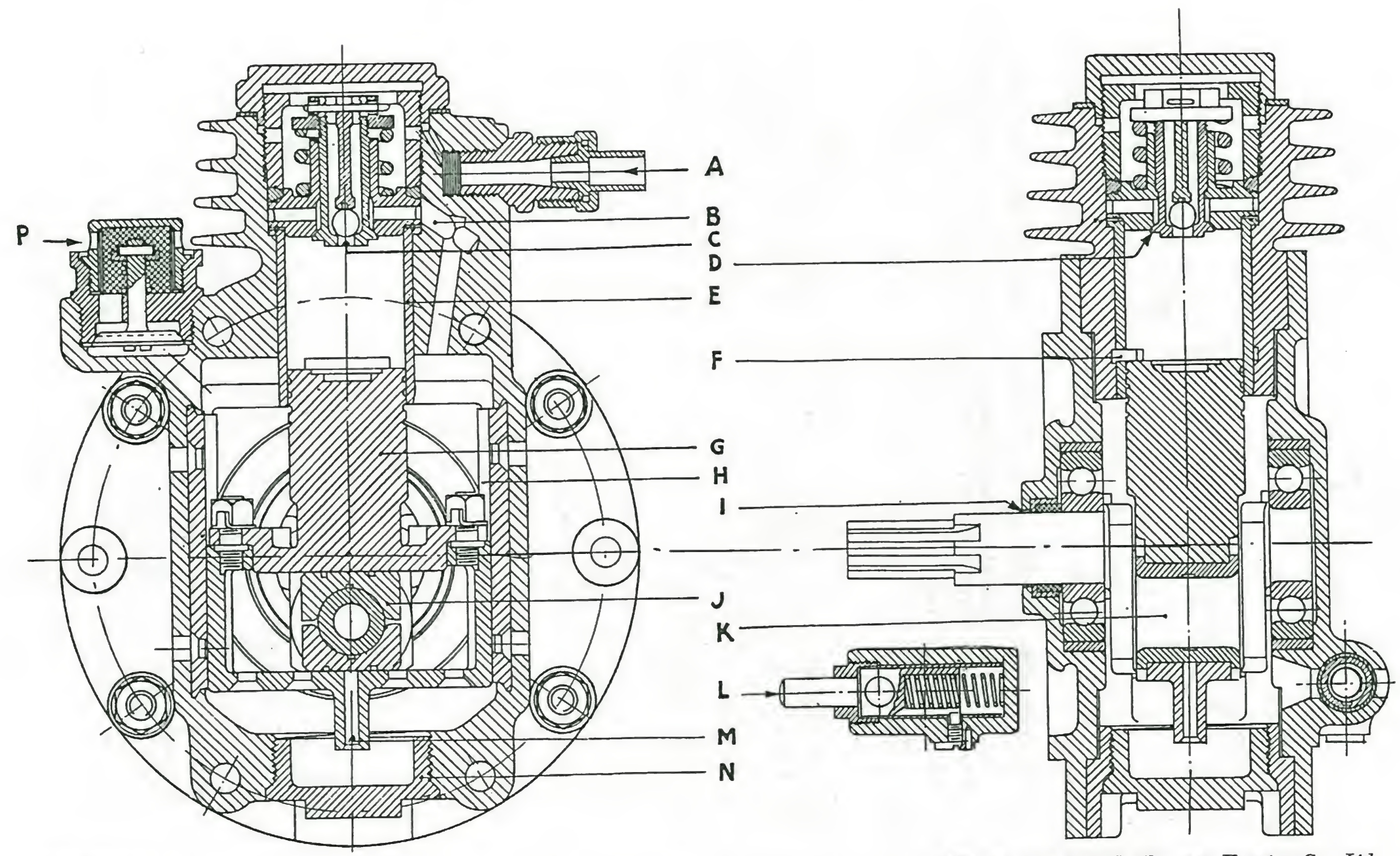
(iv) All studs should be checked for tightness and lugs for cracks.

(v) Butterfly valves may become distorted by engine backfires and should be checked with feelers.

(vi) The mixture control valve seating may be ridged and require rectification.

(vii) The accelerator pump piston and housing may be scored due to operation when dry.

Prior to re-assembly the joint faces should be checked for high spots



By courtesy of *Messrs. The British Thomson-Houston Co., Ltd.*

FIG. 8. B.T.H. AIR COMPRESSOR

A = Air bottle connection.
B = Relief valve by-pass.
C = Ball valve.
D = Relief valve.
E = Cylinder liner.
F = Cylinder port.
G = Piston.
H = Crosshead guide.
I = Oil retainer.
J = Crankpin bearing.
K = Crankpin.
L = Oil level valve.
M = Plunger.
N = Drain plug.
P = Air inlet valve.

and rectified as necessary. Ducts should be thoroughly cleaned and any dope, corrosion, or foreign matter removed. All washers should be renewed and approved jointing only used.

The calibration of the various components of the carburettor is explained in the chapter on "Engine Build," page 63.

Oil Pumps. These are for the most part of the gear type although plunger and vane types are fitted on some of the early engines. With regard to the gear type of pump, the side clearance of the gears is critical if a good suction-head performance is to be maintained. Diametrical clearance up to ·010 in. and tooth backlash up to ·020 in. are not likely to adversely affect the performance of these pumps, but the makers' figures should be the guide.

On some pumps the gear teeth are backed on the leading side on the driving wheels and on the trailing side of the idler wheels, to relieve pressure due to trapped oil. Similar results can be realized in other ways. For instance, in another design grooves are incorporated at the bottom of the gear chamber.

Fuel Pumps. Diaphragm pumps normally employ fabric diaphragms. The valves fitted are very light and backed by weak springs so that the pumps can operate at any altitude. If large suction lift is required, the valves must not leak. A drain is provided from the chamber behind the diaphragm to carry away any fuel that leaks through the fabric. A gland is provided around the operating mechanism to prevent fuel passing into the engine crankcase.

Dry suction lifts up to 18 ft. can be obtained with these pumps at low speeds if the valves are in good order, but the efficiency decreases if leakage occurs.

Petrol absorbs up to 20 per cent (by volume) of air and has a high vapour pressure. At low pressures, such as those which obtain at altitude or slow running, air tends to come out of solution particularly under agitation produced by pumping. This excess air is given up to the fuel system.

Air vessels are sometimes fitted to trap air passing along the pipes. This also replaces air lost from the vessels as it is liable to be dissolved by the fuel.

An air vessel on the suction side of the pump permits flow of fuel along the pipe line to continue whilst the suction valve is closed and eliminates hammering, in addition to increasing the quantity delivered.

When the air vessel is fitted on the delivery side of the pump, the supply is at a much more uniform pressure.

Diaphragm type of pumps require special attention at complete engine overhauls when the diaphragms should be changed because of the risk of deterioration which may occur to varying degrees, according to the fuel in use and the conditions of operation. When refitting or renewing a diaphragm it should be in the fully extended position when finally clamped up. The pump should then be subjected to a functioning test on a rig with a 12 ft. suction head, and under conditions similar to those when fitted on the engine.

Compressor. There is not likely to be much to do to this apart from a

thorough cleaning of the unit, and the removal of carbon from the valves.

The makers' instructions as regards the quantity and grade of oil to be replaced should be followed.

Sparking Plugs. These should be dismantled, thoroughly cleaned, and re-assembled with the correct gaps. They should then be tested on suitable apparatus to ensure that they function satisfactorily under 100 lb. per sq. in. pressure.

Attention is called to the following points—

(i) Inspection after stripping, should be made for loose mica washers, cracked insulators, bent, loose, or burnt electrodes, damaged copper jointing washers, crossed threads, etc.

(ii) Mica insulators should never be cleaned with an abrasive material and should finally receive a high polish, applied by spinning in a lathe, using a soft felt cloth.

(iii) Never set the gap by bending the electrode because ample adjustment can be obtained by turning the electrode prior to finally tightening the gland nut.

(iv) A plug, prior to insertion in a plug tester, must be quite dry and free of petrol.

(v) A standard jointwasher should be used because if it is too thin, the carbon at the bottom of the last thread may cause the plug to grip unduly, and loosen the insert when removing at a later date.

(vi) Before inserting a plug into the cylinder, smear the threads with a paste of graphite and grease.

Starters

Starting magnetos and motors of electric starters will not be touched by the ground engineer holding a "D" licence, but should be returned to the constructors. The mechanism of an electric starter, apart from the motor will, however, be subjected to inspection for defects in the same way as a hand starter, and on re-assembly the throw-out gear must be carefully adjusted in accordance with makers' instructions. Inertia starters should be returned to the constructors if they are not functioning satisfactorily, as without the necessary equipment for setting the clutch for the particular engine for which the starter is required, unsatisfactory functioning might result.

The principle of the inertia starter is as follows—

Energy, stored up in a flywheel revolving at high speed, is imparted to the crankshaft of the engine to be started.

The "Eclipse" inertia starter provides for the energy to be imparted to the flywheel either by hand or hand and a small electric motor. The starting handle is geared down about 150 : 1 and the energy is imparted from the flywheel to the crankshaft through gearing. A compression spring is incorporated to reduce the shock at the moment of engagement. When the engine fires, disengagement is automatic, but it can also be effected by hand.

The principle of the gas starter is as follows: A combustible fuel or mixture is supplied under pressure through the gas distributor to each cylinder during its firing stroke.

The cylinders are fed with the mixture in their appropriate firing order. During the ensuing rotation of the crankshaft, the contents of the cylinders are fired by means of a hand-starting magneto which operates through the distributor of one of the magnetos to the sparking plugs. One form of gas starter comprises a bottle of air compressed to about 200 lb. per sq. in., an air pump, atomizer, primer, and accessories, such as pressure gauge, piping, etc. Inspection of these parts should present no difficulty, and the ground engineer should become familiar with the detail, if the engine is equipped with one for starting purposes.

Attention should be paid to the valve units in the cylinders, because weak springs or leaky and distorted valves will result in failure of an engine to start.

Another form of gas starter comprises a complete starter unit, consisting of an air compressor driven by a small two-stroke petrol engine. If this type of starter is used, a knowledge of two-stroke principles will be required, otherwise the overhaul of the unit should present no difficulty to a ground engineer who already holds a "D" licence. A.P. 1181, Vol. II, *Gas Starter Systems for Aero-engines*, obtainable from H.M. Stationery Office, gives full details of these starters.

The Viet gas starter is in general use on the Continent, and, to some extent, in this country. When it is fitted on an aircraft, a Hertzmark or B.T.H. air compressor is fitted on one of the engines to supply the air bottle with air.

The ground engineer holding a "D" licence would normally only be concerned with the compressor and its drive.

The Farman starter, in which a cartridge is exploded in a pistol to provide the initial cylinder pressure to start the engine, is part of the engine, and when fitted would have to be inspected to ensure that it functions satisfactorily.

The Coffman starter supplies the power for engine starting by means of an electrically ignited solid fuel cartridge. The pressure resulting from combustion of the fuel causes a piston to travel down a cylinder. An extension shaft on the forward end of the piston engages a clutch as the piston commences to travel and further movement causes rotation of the drive shaft to the engine through intermediary helical splined pieces.

The operation of the exhaust valve is automatic and the piston returns under load from a spiral coil spring.

A cartridge is used for each engine start and the intensity of combustion can be varied to suit engine conditions by the provision of a range of cartridges.

Engine Build

Re-assembly of the engine will commence after all the rectification has been carried out, and it is very desirable to re-assemble the parts with plenty of oil, preferably castor, if the engine is to be "run-in" on that oil.

Cleanliness at all stages of engine build is important if scoring of pistons, cylinder walls, and bushes is to be avoided. Assembly should

proceed in the order prescribed by the constructors in their various handbooks and instructions, as otherwise trouble may be experienced. As examples of what I mean, it may be stated that in assembling or dismantling cylinders of a certain type of radial engine, damage is likely to be done to piston skirts if for any reason the instructions laying down the order of assembly are not carried out. It is also important that where parts are serially numbered they are fitted in their correct positions. It is quite usual for the following parts to be marked to ensure correct assembly: Master and articulating connecting rods. Bearing shells. Piston, cylinders, valves, valve spring collets. Tappet guides, push rods, camshaft bearings, etc. Mixing of valves, where different materials are used for the inlet and exhaust valves, might result in trouble during engine running, and for this purpose the material specification is usually stamped on each valve.

A thorough knowledge of the oiling system is required to ensure that all oil-ways, passages, grooves, troughs, banjos, and catchers will perform their particular function, and that glands are fitting properly. The position of oil squirts and jets should be checked to see that the oil is directed in the right direction; oil pipe unions and oil plugs should be tested for oil tightness.

The various constructors have, in many cases, established definite procedure, necessitating the use of special jigs and equipment, for carrying out certain of the more important component assemblies, and the ground engineer should familiarize himself with these where applicable. For example, the tightening of connecting rod caps may entail the use of a spring-loaded nut spanner which automatically releases at a pre-determined load. If the split-pin holes do not then line up the nut will have to be faced on the underside. Another example relates to the process of fitting and bedding valve seatings to heads and subsequent cuttering to correct dimensions. A constructor calls for the lapping of the valve spring retainer split collets to the grooves on the valve stem, after which they must be treated as integral parts. Another constructor recommends fitting and removing cylinders only when in a vertical position on the crankcase, and whilst a cylinder is being withdrawn the piston must be kept moving up and down the freely lubricated cylinder. The object of this procedure is to avoid circumferential scores, due to trapped grit, which might otherwise be a source of trouble.

Roller bearings should receive special attention during assembly into an engine, and it will be found that in many cases the rollers can be held in position on the inner race by means of an elastic band whilst the outer race is being assembled. Failures associated with roller bearings, apart from those attributable purely to normal wear and tear, are usually due to one of the following—

(i) Lack of lubrication.
(ii) Incorrect clearance.
(iii) Malalignment.

The following points should be remembered in connection with each of these headings.

(i) Every care should be taken to see that oil feed holes, passages

and grooves to the bearing, are quite clear and that the parts are assembled with plenty of oil. If the oil film between the rollers and one of the tracks is destroyed, disintegration of the hardened surface of the race must soon occur.

(ii) Lack of roller clearance in a bearing will produce a tendency for individual rollers to bind, resulting in the load being localized with consequent damage to roller and track. This condition might be accentuated or relieved as the part becomes hot. Close adherence to the makers' recommended clearances and methods of checking same is necessary to ensure satisfactory functioning.

(iii) Malalignment may occur as a result of one or other of the races being eccentric due to the housing being distorted or worn. Again the inner race may be slack on its shaft, or the locating shoulder may be out of square or may have received damage which prevents the race being driven home. The nut which holds the race in position may be slack, and it must be remembered that this nut may be right-hand or left-hand, according to the direction of rotation of the shaft.

With the recent introduction of needle roller bearings it may be of general interest to mention a few points relating to their use.

The main advantage of these bearings are—

(i) They can be accommodated where space makes larger rollers unsuitable.

(ii) The long roller provides a greater length of contact for carrying the load, thus allowing a considerable reduction in diameter.

There is a greater tendency for long rollers to "skew" when running, and accuracy in manufacture becomes all important. The bearings are more suitable for reverse loads such as those occurring when used as bearings for rockers, push rod ends, etc.

Diametric slackness is essential, particularly for high speeds, with the result that the rollers rotate on their own axes only when under load, and slide without rotation when free. Bearings must not be fitted up with rollers crowded together so that no play is left. End slackness is equally important and provision must be made to adequately lubricate all moving parts.

The back lash of the trains of gears to the camshafts, magnetos, and accessory drives must be checked, using the methods and apparatus indicated by the engine manufacturers. The back lash of important gears should be checked at a number of positions, care being taken that no dirt is present on any of the teeth.

It is important that checks of assemblies are made and important clearances duly recorded at all stages of erection. The centralization of the crankshaft requires every care so that it is correctly located in the crankcase. Similarly, in the case of certain inline engines, the bedding of the crankshaft on its bearings in the crankcase will have to be checked with mandrils, as used by the constructors. Care must be taken that the appropriate nip of the bearing cap is provided, and when roller bearings are concerned that the required roller clearance is not absorbed.

Particular attention should be paid to the clearance and end float of all white-metal, cadmium and lead bronze lined journal and connecting rod bearings, and also the method of checking and obtaining

these clearances, both from the point of view of the life of the bearings, and the oil consumption of the engine. It is not unusual to bed connecting rods with bearings fitted to oversize mandrels to obtain these results.

The question of tightening of nuts is dealt with in Inspection Leaflet No. 132 (A.P. 1208), and it is desired to stress the importance of using only those spanners designed for a particular nut, component or purpose, as otherwise parts may be stretched, distorted, or damaged. Stainless steel B.S.F. and B.A. studs and nuts are liable to seize unless free engagement is provided by selective assembly.

A liberal supply of oil should be used when tightening large nuts with tab washer locking, in order to reduce the risk of shearing a tab, if the nut suddenly bites into or grips the washer.

The importance of carefully split-pinning the main components, such as connecting rod bolts, is a matter which cannot be too fully stressed. The tendency is to provide reamed holes and to select pins that give a slight interference fit, that is to say, they may require a gentle tap to make them enter. The split-pin is entered so that the head fits snugly into the slot of the nut. One leg is bent over the top of the bolt, and the other down the side of the nut.

The elastic limit of piston ring material in conjunction with the design should permit a ring to be opened sufficiently for fitting on to a piston without causing any permanent set or distortion, provided normal precautions are taken. Distortion might have detrimental effects on the oil consumption of an engine due to the destruction of the oil film. In the same way an increase in permanent set would raise the cylinder wall pressure, which might reduce the oil film to such an extent that excessive wear resulted. It will be seen that the fitting of a ring to a piston is important and the procedure for removing rings should be employed when refitting them.

If cylinders have been ground oversize, rings should be obtained which are a similar amount larger on nominal dimension. Normally oversize rings are available in steps of ·005 in. Piston rings which permit exhaust gases to pass will encourage cylinder wear because of the destruction of the oil film. The seal is assisted in the case of the top gas ring by gas pressure acting behind the ring. This is dependent on the efficiency of the seal between the side face of the ring and the groove in the piston, which must be perfectly flat. For this reason piston rings are sometimes ground and lapped on their side faces. The piston material must be sufficiently resistant at elevated temperatures to maintain a flat groove for the side face of the piston ring to bed on to.

Gas rings with 1° chamfer from the middle of the contact face are sometimes used and it should be realized that this chamfer has the effect of doubling the loading per square inch on the cylinder wall. Such rings will bed in quickly, although wear will take place much more rapidly if lubrication is inadequate. Care should be taken to see that piston and scraper rings are fitted and disposed around the engine in the manner, as regards gaps, chamfers, loadings, etc., specified by the makers. Excessive piston clearances permit rings to wear oval with

resultant loss of efficiency as regards maintaining the oil film. For this reason some engine builders stock oversize pistons.

Cylinder distortion will impair the effectiveness of gas tightness of a piston ring in spite of pressure loading behind the ring. Furthermore, a high-class cylinder bore finish is of no avail if distortion due to mechanical effort is permitted. For these reasons the engine-makers' instructions for tightening the bolts securing detachable cylinder heads must be followed. It is equally important in the case of monoblock constructions if water and oil leaks and even cracking of the blocks are to be avoided.

When fitting cylinders to split crankcases of rotary engines, careful scraping of the crankcase spigots must be made, and when the two halves of the crankcase are subsequently tightened up with the cylinders assembled, "go" and "not go" plug gauges must be tried in the cylinder bores to safeguard against excessive "nip" and resultant ovality. In the same way where cylinders are secured by locking rings, as in the case of the Siddeley range of engines, the makers' instructions must be carefully followed. The ring should be gently tapped all round with a hide hammer as the locking screw is tightened, and only the standard spanner should be used.

Overtightening may distort the barrel, and undertightening may enable the cylinder to become slack on subsequent running.

Several types of poultice head cylinder construction may be encountered, which require removal of studs and careful scraping of surfaces if heads or headers have to be changed. In these cases the makers' handbook instructions should be followed.

The compression ratio of an engine is established on the Type Engine, and must not be exceeded on subsequent engines, except in the case of normal rectification of surfaces during overhaul which will tend slightly to raise the compression ratios, but within permissible limits.

An increase of compression ratio will give an increase of power which might overstress the parts. There is also a risk of detonation occurring.

It is possible to increase the compression ratio by reducing the clearance volume on different types of engines as follows—

(*a*) By fitting higher compression pistons.

(*b*) Where cylinder heads are normally detachable from the barrels, by fitting heads with decreased combustion space.

(*c*) By removal of packing ring, sometimes fitted under the holding down flange of the cylinder.

(*d*) Where cylinders are screwed into the crankcase or separate adaptor rings, by screwing the cylinders further into their location.

It is advisable therefore occasionally to check the compression ratio of engines, which is done as follows for each of the conditions cited above.

(*a*) Check weight and part number of piston, also height from axis of gudgeon pin to crown.

(*b*) Effect a volumetric check of the combustion space of the head with thin oil. To do this the head is inverted and set up with the joint face horizontal.

(*c*) This can be checked visually, it being only necessary to measure the thickness of the ring, if fitted.

(*d*) Cylinders of rotary engines are checked from centre of rocker standards to crankcase, with a height gauge. In another case the height is controlled by the cylinder locking ring gap.

With regard to check (*b*), it is desirable to ascertain the true cylinder capacity from time to time and the following information is supplied for this purpose.

Determination of Compression Ratio by Direct Measurement

(*a*) Fill the space in the cylinder with a suitable medium and then measure the quantity used. This operation is carried out with the piston at the top and bottom positions in the cylinder respectively. The medium recommended is a thin mineral oil. It should be noted that paraffin is unsuitable, and liable to give false readings owing to leakage which might take place.

(*b*) The test should include at least one cylinder on each bank in the case of "V" type engines, and the cylinders with the minimum and maximum stroke variation, and one with a master rod in the case of radial engines. At least two cylinders should be tested on "in line" engines.

(*c*) In carrying out the test the valves will be fitted in the closed position, and this may necessitate the removal of part of the valve gear. Orifices will be closed with their respective components except one sparking plug hole through which the medium is entered.

The standard piston with its rings will be assembled in the engine, the rings having previously been lubricated with thick tallow to prevent leakage of oil.

(*d*) Before pouring in the oil, the engine should be tilted until the sparking plug hole face is, as far as possible, horizontal. This will be facilitated if the engine is mounted on a tilting stand.

Oil is then poured into the cylinder from a graduated measuring glass, care being taken to avoid formation of bubbles as the cylinder becomes nearly full. The engine should be rocked in order to release any trapped air.

(*e*) It is usual to deduct about 1 per cent from the measured quantity of oil to allow for some clinging to the measuring vessel.

(*f*) The compression ratio will be arrived at as follows—

$$\text{Compression ratio} = \frac{\text{the swept volume} + \text{clearance volume}}{\text{clearance volume}}$$

As the assembly of an engine nears completion the various accessories such as magnetos, carburettors, oil pumps, etc., will be assembled. Oil pumps and small auxiliary oil pumps should have been run on a rig at speeds and under conditions as regards pressures and temperatures similar to those when functioning normally on the engine.

If magnetos have been overhauled either by a ground engineer holding an "X" licence, or the manufacturers, suitable functioning tests would already have been carried out.

Care is required in fitting magnetos to the engine to ensure that they

are properly aligned, if of the platform type, otherwise the laminated spring drive will certainly give trouble.

If they are spigot mounted the gear wheel clearances are important.

Magnetos should be timed fully advanced with contact breaker points set to break with the correct gap. Normally the timing can be set to within $\pm \frac{1}{2}°$, and magnetos can be synchronized to the same limits. If the points are set too far apart the timing will be advanced and the spark intensity will be impaired if the break does not occur in the most efficient position of the armature in relation to the magnetic field.

A variation in gap of ·001 in. may alter the timing as much as $\frac{1}{2}°$. A worn contact breaker arm heel will retard the timing.

There are several methods of setting the ignition timing on an aero-engine. When I say ignition timing I mean the position of the piston in No. 1 cylinder on the firing or compression stroke, or alternatively the angular position of the crankpin, at the moment the actual separation of the contact breaker points occurs.

One of the simplest methods is to remove the contact breaker cover and observe the break, or separation, of the points as the engine is turned slowly forward. This should be repeated several times, and the position of the piston in the cylinder, or the angularity of the crankpin, checked each time. The former is done by inserting a suitable gauge into one of the sparking plug holes, an arm incorporated in the gauge making contact with the crown of the piston. The angularity of the crankpin is ascertained by means of a graduated timing disc which can be attached to the airscrew shaft, or other suitable place. Certain manufacturers dispose of the timing disc altogether, the correct position for ignition setting being indicated on the periphery of the annulus wheel in the case of geared engines.

A method of checking the ignition timing consists of inserting a strip of cigarette paper between the contact points, and noting just where it is possible to pull the paper out. This will correspond to a gap between the points of approximately ·0015 in., but should not involve any appreciable error in the timing. A ·0015 in. feeler blade would be a suitable alternative to the paper.

There is an electrical method which requires the use of an ordinary flash lamp battery, a small lamp, or alternatively a bell. The circuit is made by connecting a lead from the insulated side of the contact breaker to a terminal of the battery. The lamp is then connected in series with the other terminal of the battery, and finally a lead from the lamp to the earth side of the magneto or engine.

On all rotating armature type magnetos, and those having an external primary lead, the lamp should light when the points make contact, and becomes extinguished when the points open. On other types of magnetos the light should become dull instead of extinguished when the points open. This is due to the fact that magnetos having a permanently fixed primary lead to the contact breaker offer an alternative electrical circuit when carrying out this test. It must be noted in this connection that on rotating armature type magnetos the centre or earthing screw must be removed before this test is commenced.

Tests of carburettors vary according to the type, but a number are

general for all carburettors, and the most important of them will be mentioned.

1. A flow test is made to ensure that a supply of fuel is available at the jets, well in excess of the full throttle consumption of the engine. The test is made at the minimum fuel head at which the carburettor is expected to function, the plug under the jets is removed, and fuel is run through from the float chamber and collected in a measuring vessel.

2. A flooding test is imposed on the needle valve in the float chamber. This is done by supplying fuel at a pressure equal to the maximum head for a certain time, during which no flooding should occur, even though the carburettor is tilted 15° in all directions.

3. The level of the fuel in the float chamber is checked and adjusted if necessary.

4. The mixture control valve requires an air leak test, normally about 1 lb. per sq. in., during which no leakage should occur.

5. The jets are calibrated on approved apparatus to ensure that the correct petrol flow, in cubic centimetres per minute, is obtained.

6. The range of mixture control on vacuum type carburettors is checked by testing the carburettor complete with its elbow and air intake on a blower plant, providing an artificial depression equivalent to that obtained when the carburettor is functioning on an engine at full throttle and normal r.p.m. The specific fuel consumption with the mixture control open and closed is then read direct from the flowmeter. A check can also be made with the carburettor fitted to the engine if the mixture control range does not exceed, say, 15 or 20 per cent. Erratic running of the engine may be anticipated with the mixture control full open, when a larger percentage of control is provided, and in these cases it is possible to enrich the mixture for the test, either by increasing the size of the main jet, or by a constant auxiliary supply of petrol direct into the induction pipe or air intake.

7. With those carburettors incorporating heater jackets it is necessary to check the cover joints to see that they are properly made, by subjecting the system to a pressure at least 50 per cent in excess of the normal pressure under engine running conditions.

8. If an accelerator pump is fitted its correct functioning should be checked by a number of quick accelerations, the displacement of petrol being measured at the same time.

9. If the butterflies and spindles are oil heated, a pressure test with hot oil is required to test glands and joints.

10. Some modern carburettors are rendered automatic by the provision of exhausted capsules to control the enrichment and altitude jets respectively. The settings must always be carried out in accordance with the maker's instructions. Mixture control, providing full strong and full weak positions only, is sometimes incorporated.

The capsules must respond to definite deflections according to changes in temperature, barometric pressure in the case of the altitude capsule and boost pressure in the case of the enrichment capsule.

On overhaul, capsules should be checked for leakage or damage and to ensure that the required rate of deflection has not altered.

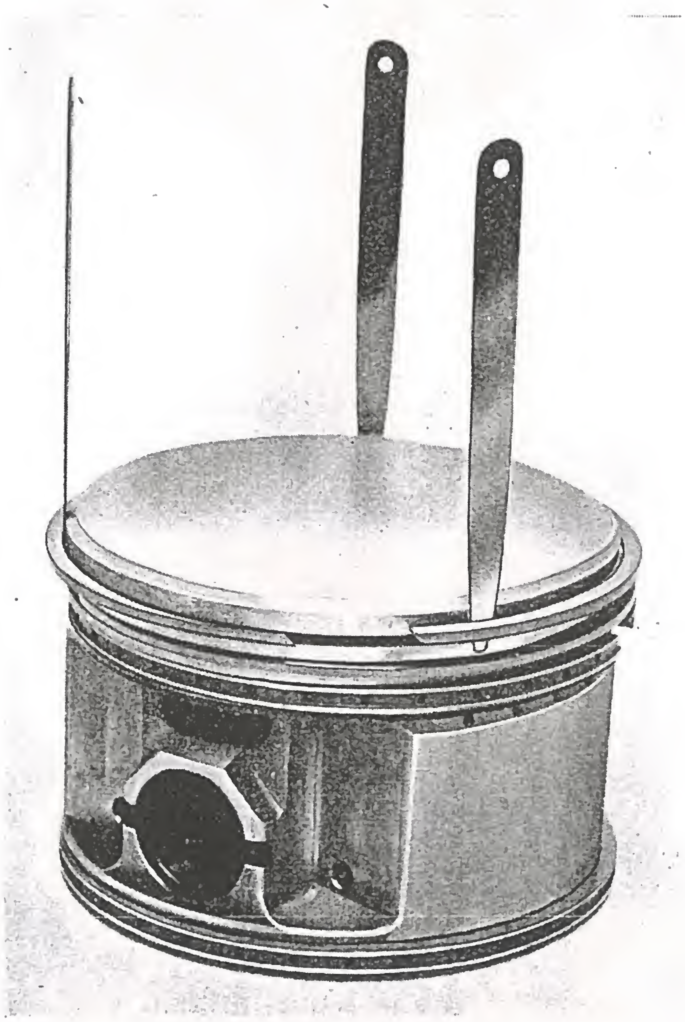


PLATE XI. A GOOD METHOD OF REMOVING AND FITTING PISTON RINGS

PLATE XII. SCALING AND CORROSION DUE TO EXCESSIVE TEMPERATURES

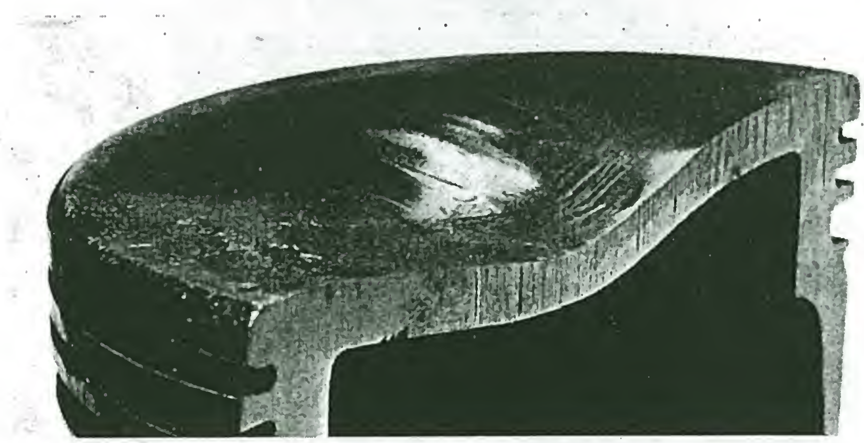


PLATE XIII. SUNK PISTON CROWN RESULTING FROM EXCESSIVE TEMPERATURES

Due to very weak mixtures, detonation, etc.

Engine Tuning

Re-assembled engines must be submitted to bench tests to prove out any new parts that have been fitted, and to show up any faults of assembly, but prior to these tests, running in and "tuning" are of first importance, particularly if new major parts have been fitted. Starting up an engine from cold requires special mention. Correct priming to ensure satisfactory starting is a matter of experience, and over-priming with fuel must be avoided as it may result in the oil film on the cylinder walls being destroyed. Excessive flooding of the float when down-draught carburettors are fitted is equally undesirable for the same reason.

If at any time during the preliminary running-in of new parts the surfaces become dry, it is almost certain that scoring will result, and in the case of cylinder bores the scoring may be serious, and similar scoring is likely to be indicated on the piston rings and pistons also. It may be so serious that normal methods of rectification will not restore the original condition. If, however, the parts behave satisfactorily during the running-in and endurance tests, it is probable that a surface will have been formed which will improve on subsequent running.

In order to safeguard against the possibility of cylinder dryness occurring, some people favour upper cylinder lubrication, that is to say, whenever it is necessary to open the throttle after starting up an engine, a quantity of lubricating oil is sprayed into the air intake at the same time, and possibly at intervals during the running-in period.

Running-in and tuning an engine with castor oil is preferable to mineral oil, and much improved surfaces of piston rings, piston skirts, cylinder bores, etc., will result. The constructor's instructions regarding an initial supply of lubricant to certain parts of an engine, prior to starting up, should always be observed, and with certain engines the valves of the bottom cylinders should be raised slightly to permit any accumulated oil in the cylinder and induction pipes to be released.

An accumulation of oil in the lower induction pipes may occur through drainage from other parts of the induction system, and from the combustion chamber as a result of crankcase oil passing through the oil holes in the gas ring grooves of the piston, on shutting down after a previous run. It is possible to turn some engines by hand without displacing the oil in the induction pipe, but a sudden suction resulting from the initial firing in one of the cylinders, might carry the oil through and damage the cylinder. Where induction pipes incorporate drain plugs, they should be removed prior to a run, and when refitted securely locked again.

Serious trouble may also result if petrol or water are trapped in the combustion chamber. The former could occur through a leaky priming system, and the latter by a faulty header or leaking cylinder liner joint.

With engines fitted with lead bronze bearings, it is undesirable to turn the crankshaft if they are not adequately lubricated. Hot oil at normal running pressure, should be pumped into the system for from 5 to 10 minutes to ensure that the bearings are adequately lubricated.

An engine should only be started up when it has been ascertained that the parts are adequately supplied with oil, and should be run initially at a speed just sufficiently high to ensure that parts such as cylinder walls, etc., relying on splash and oil mist, are adequately lubricated. The speed and load should be progressively increased as recommended by the makers. Observation should be made throughout this period of running for water leaks from jackets, oil leaks at unions and joints, etc., general and local over-heating, vibration, detonation, slow running, acceleration, etc.

Vibration may be associated with mal-alignment of the engine on the brake, quite apart from causes due to faulty ignition or carburation, dealt with under Section "Location of Faults."

Detonation may be suspected if puffs of smoke are noted in the exhaust flames, but a more searching check can be made with the Farnborough indicator, but as this is not normally part of the workshop equipment it becomes necessary to adopt an "audible" check; here again, however, to get any degree of reliability the engine exhaust should be properly silenced, but with practice it is possible to determine, within 50 r.p.m. the speed at which detonation commences.

The engine should be run at full throttle or M.P.B., and the observer should be as near as practicable to the cylinders, taking note of intermittent and regular detonations.

The effect of exhaust manifolds may easily advance the detonation period by 100 r.p.m.

The initial pressure after the first part of the charge has ignited may be as high as 450 lb. per sq. in., and the resultant momentary pressure when the "pink" takes place may be several times as great.

The danger from detonation is excessive overheating followed by burning, and sometimes caving, of the piston crown, burnt sparking plugs and exhaust valves.

If an engine runs a power curve with standard fuel and a repeat power curve with doped fuel, the two curves should be of similar character if detonation is absent.

Slow Running. This test should be carried out without any artificial heating to the air entering the carburettor, and whilst it may be done with the airscrew fitted, the inertia will be far greater than that of the fly-wheel and coupling on the test bench.

The valve clearances should be accurate before the test is made, and the sparking plugs must be clean.

Valve clearances should be checked as indicated by the makers. Unreliable results will be obtained by shutting the engine down, and then checking clearances hot, particularly with austenitic valves. It is known that on some engines fitted with these valves, the expansion is very great, and the sudden cooling of the valves on shutting the engine down may result in the clearances actually increasing, it being a matter of minutes before the other parts have cooled sufficiently to effect a correct compensation.

Failure to secure satisfactory slow running has also been traced to leaking glands, fitted on the fan spindles of certain supercharged engines.

Acceleration. The carburettor should be tuned to give satisfactory

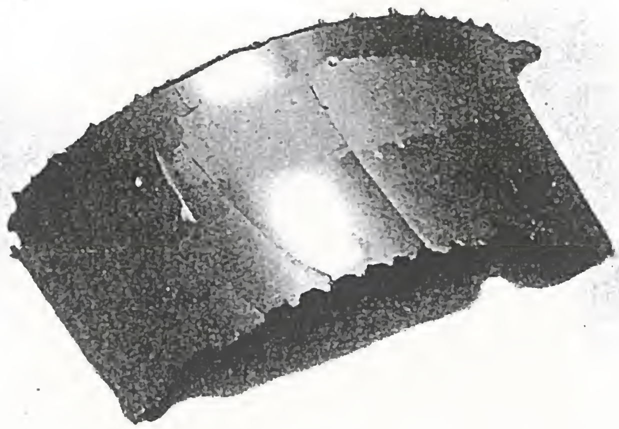


Plate XIVa. Film of Electrically-deposited Metal, which Became Detached During the Subsequent Grinding Operation

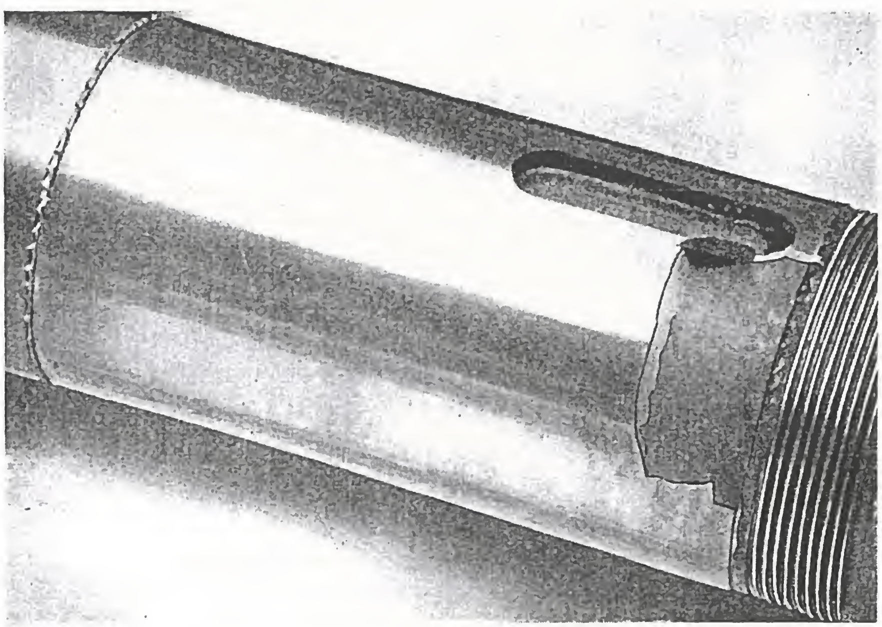


Plate XIVb. The Shaft, showing where the Film of Metal became Detached

slow running at about 80 per cent below normal r.p.m., and the engine should respond to snatch openings of the throttle both at economic normal and rich settings.

Faulty accelerations are much more likely to occur when opening up from slow running than from take-off speeds and above.

OIL SYSTEM. With regard to the oiling system it is usual, where an auxiliary crankcase feed forms part of the system, to calibrate this fitting when the oil pump is tested on the rig, and under normal operating conditions as regards pressure and temperature. High oil pressures usually result in high oil consumptions, and a relief valve should be adjusted to show a pressure near the bottom of the rating. In the same way engines should be passed off test with oil consumptions as near to the bottom of the rated figures as possible. High oil consumption may be due to leaky oil pipe unions, tappet guides and breathers, excessive clearances of bearings, leakage past the gas rings, etc. The latter can be located on one or more cylinders if the engine is fitted with separate stub pipes. The use of a lubricating oil for testing engines inferior to that used on the type engine is not permitted.

INDUCTION SYSTEMS. These will have already been subjected to a smoke test to ensure that all joints on the system are properly made. This necessitates the removal of push rods on radial engines to ensure that all valves are seating. Alternatively, valves are often tested by pouring paraffin behind the seatings and applying air pressure at 10 lb. per sq. in. when excessive leakage would necessitate re-grinding the leaky valves on their seatings.

The smoke test is carried out by placing a piece of smouldering rag into a box fitted on to the induction elbow. Air is supplied to the box from a hand pump, or air pressure supply, and the smoke is forced through all the passages of the induction system.

The carburettor will have already been proved to function satisfactorily on the blower plant, but a check on the engine will show if there are any flat spots or irregular running. The flowmeter reading is a good check of the correctness of the carburation, but a further check can be made by running the engine at nine-tenths of full throttle in subdued light with stub pipes fitted, and noting the exhaust flame colours, and whilst they may appear to vary slightly with each type of engine, according to the distribution, the generally recognized symptoms are as follows—

Very rich mixture.	Smoky and long irregular blue flames.
A rich mixture .	Long narrow blue flames.
Normal mixture .	Short bluish Bunsen type of flame.
Weak mixture .	The blue flame of the normal mixture changes to a narrow transparent dull green.
Very weak mixture	An almost transparent flame with a red centre and possibly intermittent "popping back" in the carburettor.

The red coloration does not give any indication of the correctness of the distribution, and is largely associated with the lubricating oil.

The black smoke with the very rich mixture cannot, of course, be noticed if the test house is quite dark.

If a smoky exhaust is obtained during slow running this is an indication that the slow running jet requires adjustment.

Weak mixtures cause high peak temperatures around the combustion chamber surface, due to the slow and incomplete burning of the fuel.

The highest economical mean pressure is obtained when the mixture is so proportioned that all the oxygen in the air combines with the hydrocarbons of the fuel.

The products of perfect combustion are CO_2 and N_2, and the mixture of petrol to air should be about 1 to 15 by weight at ground level. H_2O is also present

If the carburettor is fitted with a power jet a check should be made to see that the jet does not come into operation so that the nine-tenths power fuel consumption reading is adversely affected. The effect of this jet is to give an economical cruising range to the carburettor, at the same time to provide ample enrichment for full throttle positions.

The position of the thermometer for taking air intake temperatures should be standardized for each type of engine, as the corrected brake h.p. may otherwise be inconsistent. The position should be such that the thermometer is unaffected by radiant heat. In cases where the air is heated by passing over an exhaust pipe the selection of the position is even more important. Air should be drawn from outside the test house, free from exhaust fumes and dust which blows up on windy days. The use of a fuel inferior to that approved for the type engine, or those containing Tetra Ethyl Lead, is not permitted, unless it has been authorized. The effect of the leaded fuel on certain materials sometimes used for valve seatings and valves is known to be detrimental. It is also well known that leaded fuel in the presence of water readily attacks magnesium alloy parts.

The presence of water in storage tanks can be readily detected by means of specially prepared strip paper having a brown preparation on one side.

The strip is attached to a bob weight at the end of a piece of string, lowered to the bottom of the tank, and left there for two minutes. If H_2O is present the preparation will disappear, leaving the paper white.

FUEL PUMPS. There are two main types of fuel pump, the gear and the diaphragm. When gear type fuel pumps are fitted to engines it is important that fuel is circulated whilst the engine is running, as in many designs the fuel constitutes the lubricant for the moving parts. The use of pumps designed to supply fuel to a gravity tank might cause flooding if fed direct to the carburettor. In these cases the pump is cut out for bench tests, the fuel feed from the flowmeter being taken direct to the carburettor, the pump merely circulating fuel from a tank, a check being taken to prove that the pump is functioning satisfactorily by measuring the amount delivered over a given time. In carrying out this check care is required to see that there are no air locks in pipe lines, or air leaks on the suction side of the system.

Some makers fit two pumps, one giving a direct feed to the carburettor, and the other delivering fuel to a gravity tank in the machine. They might not function satisfactorily if reversed, as the capacities and delivery pressures may be different.

With diaphragm pumps any replacement or refitting of diaphragms will entail a re-check of fuel delivery.

The ignition system should not give much trouble, but magnetos, like other accessories, must be of approved type design. Engines are run on single ignition to check the extent of the drop in revolutions per minute. This should not exceed the schedule requirements. The test is carried out at full throttle and excessive drops in revolutions per minute may be due to dirty sparking plugs, or incorrect ignition timing. The effect of advancing the timing is normally to reduce the drop in revolutions per minute.

Sparking plugs should be maintained in a satisfactory manner, by periodic dismantling and cleaning, followed by a pressure test at 100 lb. per sq. in. for functioning on re-assembly. Dirty sparking plugs have a direct bearing on engine performance on the test bench, and erratic running and loss of power may be anticipated.

The change of oil from castor to the type approved for the engine should be effected whilst it is hot. New oil is added to the tank in the ordinary way, and the castor oil is drained from the engine sump until only fresh oil passes through. A better arrangement would be to have two separate tanks, one containing the vegetable and the other the mineral oil. The one is shut off as the other is turned on; mixed oil being drained off from the scavenge side of the system as before.

Test-House Equipment

Before we proceed with the acceptance tests of an engine we must see what knowledge the ground engineer requires with regard to the test equipment, and the nature and extent of the tests that are required and designed to assimilate to some extent the flight conditions.

The requirements of the Air Navigation Directions for the testing of normally aspirated engines, i.e. those rated for performance at full throttle at sea level, have been set out in detail in Design Leaflets C1, C2, and C3 of A.P. 1208, and it is important that the ground engineer becomes familiar with them in so far as they relate to subsequent engines. Paragraph 19 of Design Leaflet C2 deals with the general requirements of the test plant, and leaves the constructor a fair amount of latitude in the selection of apparatus suitable for any particular condition.

The first requirement is that "the brake shall be capable of varying the revolutions per minute at full throttle without stopping the engine." This allows for the power curves called for in the schedule, and data such as fuel consumption curves to be properly taken, and engine performance generally observed throughout the full range of speed.

A few particulars of dynamometers fulfilling the above requirements

will now be given, but the ground engineer should have had practical experience of one of them.

HEENAN & FROUDE HYDRAULIC DYNAMOMETER. This is probably one of the best known and most extensively used. The power generated by the engine is transmitted through a coupling to a rotor. This rotor revolves in an outer casing through which water is circulated, and is mounted on bearings to permit free, though restricted, movement about its own axis. The resistance offered by the water to the turning of the rotor reacts on to the casing, which is maintained in horizontal balance by suitable weights suspended at the end of a balance arm attached to the casing. The internal resistance can be varied by means of sluices, and the water in circulation carries away the heat generated by the destruction of power. An independent cooling fan giving an air speed range of from 75 to 120 miles an hour over the engine, is used. The air speed is recorded by a water manometer, calibrated to record under a given set of conditions. In operating a strange brake, preliminary checks should be made of engine alignment, accuracy of weights and balance of the rotor casing with water in circulation, and engine uncoupled from the brake. The correct horizontal position is indicated by a pointer. A constant supply of water at a pressure recommended by the makers of the brake should be available, and no power readings should be taken outside the range for which the brake is designed.

The B.H.P. $= \dfrac{W \times N}{K}$.

N is the revolutions per minute of the airscrew shaft.

W is the load in lb. lifted by the arm.

K is the constant for the brake. If $\dfrac{1}{K}$ is unknown the formula for $\dfrac{1}{K}$ is $\dfrac{2 \times \pi \times L\ (\text{ft.})}{33000}$.

$L =$ length of the arm from the centre of the brake to the point of suspension of the weights.

THE HIGHFIELD ELECTRIC DYNAMOMETER. The engine in this case is coupled direct to the armature of an alternating current generator. The stator, or casing, of the generator is mounted on ball bearings, but is restricted in rotational movement, and provides, in effect, a swinging field. The power developed by the engine is measured by the torque reaction of the casing, which is connected by a short arm to a steelyard type of weighing machine, electrically operated. The torque can be controlled by variation of the electric circuit of the stator. The electrical power developed is used to drive a motor coupled to a fan supplying cooling air through a tunnel to the engine, any surplus energy being absorbed in outside circuits. It will be seen that the plant can be self-contained, but with an external source of electrical power the generator can be used as a motor for starting and running in an engine. The brake horse-power is calculated as previously described.

Heenan & Fell Dynamometer. The engine is mounted on a centrally pivoted torque table, free to move within restricted limits. Attached to the torque table is an arm, from the end of which weights are suspended, and the reaction of the fan impellor, or rotor, fitted to the engine, is measured in a similar manner to the two dynamometers previously described. The fan impellor rotates in a casing which is provided with adjustable outlets, so that the engine load can be varied by regulating the discharge of air.

A further requirement of Design Leaflet C2 is that "The h.p. developed by an engine shall be measured by the torque reaction of the engine." The three types of dynamometer already described conform to this requirement. There is, however, a torque reaction brake, normally used for rotary engines, which also conforms, but it is not possible to vary the revolutions per minute at full throttle. With this brake the weight is constant, but can be moved along an arm attached to the pivoted torque table to which the engine is bolted. Early forms of brake had the engine mounting above the axis of the pivot of the torque table, and errors were possible if the arm was not maintained in horizontal balance.

It should be noted that whilst the b.h.p. of rotary engines is arrived at from the formula previously quoted, this also includes the power required to turn the engine, and overcome the resistance of the cylinders to the surrounding air. Accordingly, deductions of approximately 10 per cent to 20 per cent, according to the type of engine, must be made from the gross h.p., in order to obtain the h.p. available at the airscrew.

Engine Cooling

Paragraphs 19 to 32 of Design Leaflet C2 specify certain requirements during engine testing, such as cylinder cooling, fuel, oil and air intake conditions, etc.

We will, then, briefly consider each of these headings.

Cylinder Cooling. This is probably a less serious matter with water-cooled than air-cooled engines, although in the former case excessive temperatures might cause steam pockets and resultant local trouble.

Normally the engine bench test is carried out at a uniformly maintained coolant temperature. To secure similar conditions in flight, a thermostat should be fitted in the coolant system. This relieves the pilot of the necessity to operate the radiator shutters because when the coolant temperature falls near say 75° C., the coolant is gradually by-passed from the radiator. When the coolant temperature has risen to say 95° C., the by-pass valve is shut and the system operates as a normal liquid-cooled engine.

Where liquid coolants are used, Ethylene Glycol is sometimes employed in place of water. This liquid has a boiling point of 185° C. and a freezing point of – 30° C. At 15,000 ft. it boils at approximately 160° C.

The liquid can only be used with safety up to 130° C., but as an engine would then be running hotter than with water as a coolant,

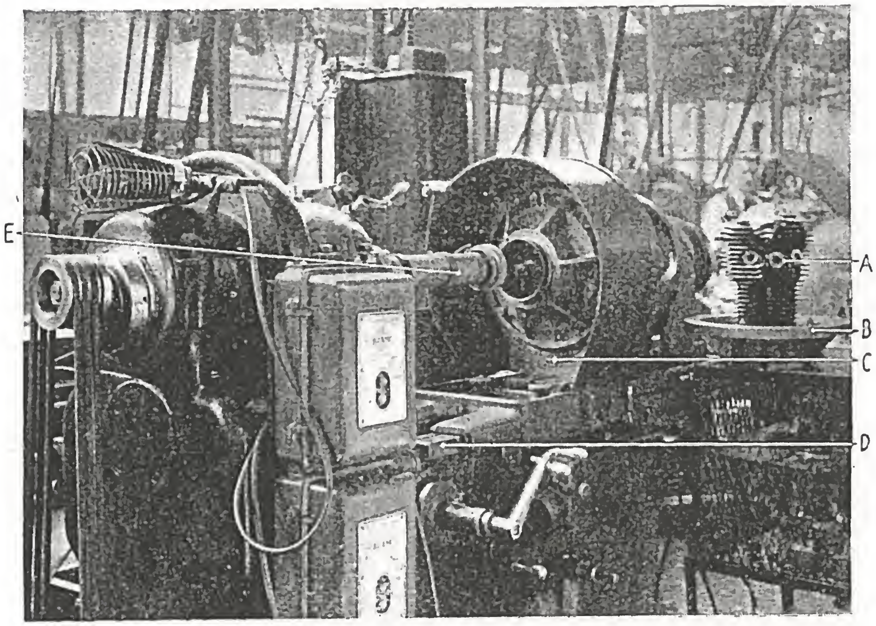


PLATE XV. GRINDING CYLINDER BORES

The cylinder *A* is screwed into the jig plate *B*, which is then bolted to plate *C* on the machine. Arm *E* carries a grinding wheel, which is driven by a shaft passing through the centre of the arm.
The cylinder is made to reciprocate backwards and forwards whilst rotating. The method of mounting the cylinder eliminates any possibility of mal-alignment, and the thickness of the walls is perfectly uniform after the operation.

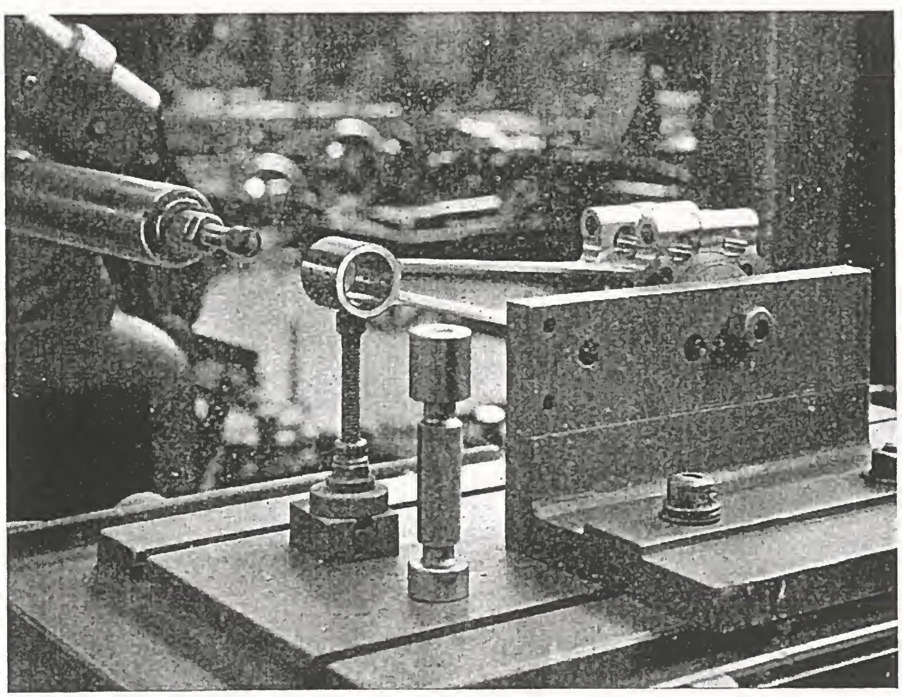


PLATE XVI. GRINDING THE EYE END OF A CONNECTING ROD
("Go" and "Not go" gauge in the foreground.)

loss of power might result, due to impaired volumetric efficiency. This drop in power is, however, more than offset by the reduced drag in the aircraft, by virtue of the fact that the radiator surface is halved.

Ethylene Glycol is expensive and must not be allowed to boil, in view of the possible loss by evaporation. If water is present, the temperature must be kept below 100° C., otherwise steam pockets may occur. It has a tendency to creep like paraffin, and all joints require special attention. It is also dangerous to the skin. It attacks ordinary rubber when hot, and special material has to be used. If it comes in contact with a hot manifold it ignites more readily than lubricating oil.

Some engines are compositely cooled, that is to say, water and steam are used. The water inlet temperature may be 95° C., and the outlet temperature 105° C. The steam generated in the header tank is carried off to a condenser and returned to the water system, by means of an injector. Much heat is absorbed in converting the water into steam.

Pressures up to 3 lb. per sq. in. may be obtained.

Pressure cooling differs from composite cooling in that there is no condenser and the system is closed. A relief valve is inserted and set to blow off at from 15 to 30 lb. per sq. in. In practice a pressure of say 5 lb. per sq. in. may be expected on "climb" and up to 15 lb. per sq. in. operating in the tropics.

A failure of the system would result in excessive steaming.

Overheating, if associated with detonation can be partially suppressed by the use of an anti-knock fuel, and to a less extent by increasing the mixture strength, but on the test bench the cylinder temperatures of air-cooled engines are largely controlled by the volume and velocity of the cooling air, and for this reason it is usual to fit thermo couples on one or more of the hottest cylinders.

A couple is formed by the union of two dissimilar metals which, on being heated at the junction, generates an electric current sufficiently strong to be measured on a sensitive galvanometer or millivoltmeter.

For the range of temperatures normally recorded on aero-engine cylinders, couples, composed of constantin and copper are often employed. A cold junction box is usually inserted in the circuit. This contains the junctions where the wires from the couple are joined with those to the galvanometer, and as long as the two joints are maintained at the same temperature ($\pm$ 5°) any E.M.F.s set up will be equal and opposite, and no appreciable error will occur.

E.M.F. is generated when the couple is heated to a temperature different from that of the remainder of the circuit.

When the galvanometer is adjusted to read zero, the temperature of the couple and the cold junction should be the same. The difference in temperature of the cold junction above or below zero should be added to or subtracted from the galvanometer reading as the case may be, to get the true temperature of the body being measured. It will be seen that the temperature of the cold junction must remain constant. This is normally taken care of by fitting it into a thermos flask and in heat-treatment shops, by employing water-cooled cold junction boxes.

Most engines have provision in the cylinder heads for the "thimble" or buried type of thermo couple, but if no provision has been made, the ring type, which fits underneath the sparking plug, is available. There is, however, a risk of obtaining erratic readings with this type of couple, owing to leakage of hot gases and exposure to slip stream, and the thimble type generally gives more consistent results and will normally show temperatures 40° to 50° C. higher than with the ring type.

A periodic calibration of thermo couples, together with their respective leads and cold junctions, should be carried out. This can be done by using a block of aluminium into which the couple to be tested is screwed, care being taken to see that a good contact between the couple and the bottom of the hole is obtained. As near to the couple as possible another hole is provided, into which a standard thermometer is inserted, surrounded by mercury. The aluminium block is heated uniformly by means of a Bunsen burner to 300° C., and as it cools down, readings of the couple under test are taken by means of a standard thermometer. A graph, showing temperature against E.M.F. or galvanometer reading, should be plotted.

Some instruments are fully compensated as regards cold junction temperatures, whilst others require adjustment prior to calibration. In both cases the instructions with the instruments should be followed.

It will be clear that when testing engines on the bench the tunnel air speed, recorded in miles per hour by pitot head or inches of Hg on a U-tube manometer, will give no indication of the air speed over the cylinder heads. This will be dependent on the form of cowling provided and the resultant spilling of air into the test house.

The temperature of magnetos during test may easily reach 90° to 100° C., and in view of the moulded parts used in their construction, it is desirable to avoid these temperatures by providing suitable cooling.

Oil System. Oil tanks should be of such a form that accurate readings can be taken. They should incorporate some form of auxiliary heating in order to maintain the oil inlet temperature at 70° C. during the test of the engine, care being taken that local heating does not occur, as otherwise there is a risk of impairing the characteristics of the oil.

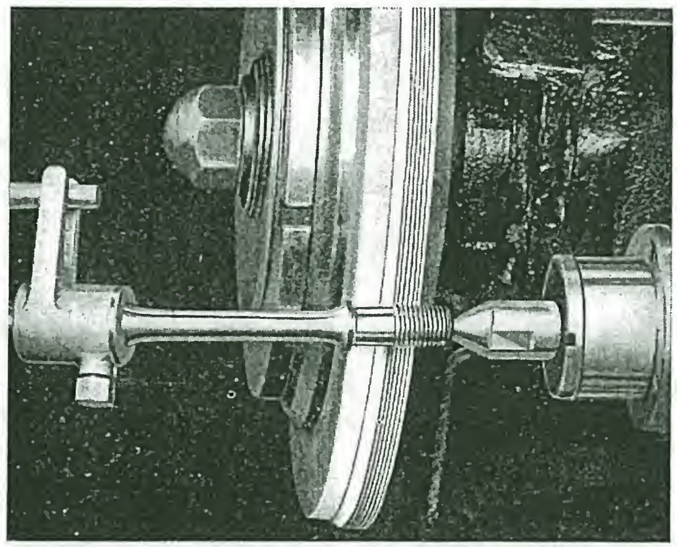
The pipes would require to be lagged with asbestos for testing in the winter in exposed or open test houses, whilst in hot weather provision for cooling the oil would be necessary.

It is undesirable to cut down the quantity of oil in circulation during a test, and it is suggested that as a minimum the equivalent of six hours' consumption should be used.

Oil filters should be fitted on all test benches in addition to any filters already incorporated in the engine. They should be large and capable of filtering the smallest particles of foreign matter. If they are provided in duplicate it is possible to clean one whilst the other is in use.

Air Intake. Artificial heating to the air entering the carburettor

during cold weather has been permitted in certain cases where the conditions are not more favourable than those in the aircraft in which similar engines are normally installed. No artificial draft is allowed to play on the air intake, and the position of the thermometer, dealt with elsewhere, is important.



By courtesy of *Messrs. Rolls Royce Ltd.*

PLATE XVII. GRINDING A SCREW THREAD ON A STUD

Ground screw threads are often specified for parts on modern engines, due to the difficulties in producing accurate threads on the special steels used, by other means.

The accuracy of ground threads is dependent on the grinding wheel. This has a number of ribs on its periphery, each of which is generated in turn to true form and pitch corresponding to the thread to be ground. The axis of the grinding wheel is off set to that of the work.

The initial trueing and periodic dressing of the grinding wheel is done by setting up a delicate micrometer cam box between the centres which hold the work. This box contains cam, stylus and holder for diamond dressing tools.

The face of the wheel is dressed first. Then a V-shaped diamond tool is fitted to the holder and the grooves are roughed out, finally with a finishing diamond tool, the exact shape of the grooves is generated.

Inspection of finished threads includes an examination of all elements on a Zeiss machine, by projecting the magnified image on to a screen on which a correct master thread is drawn; in addition close inspection for cracks is necessary.

FUEL SYSTEM. The fuel is measured by some form of flowmeter, such as the Brown and Barlow. With this apparatus fuel is supplied from a tank through a filter to the float chamber at the top of the instrument. The head of fuel should be as indicated by the makers, usually about 18 in. The float chamber connects with the body of the

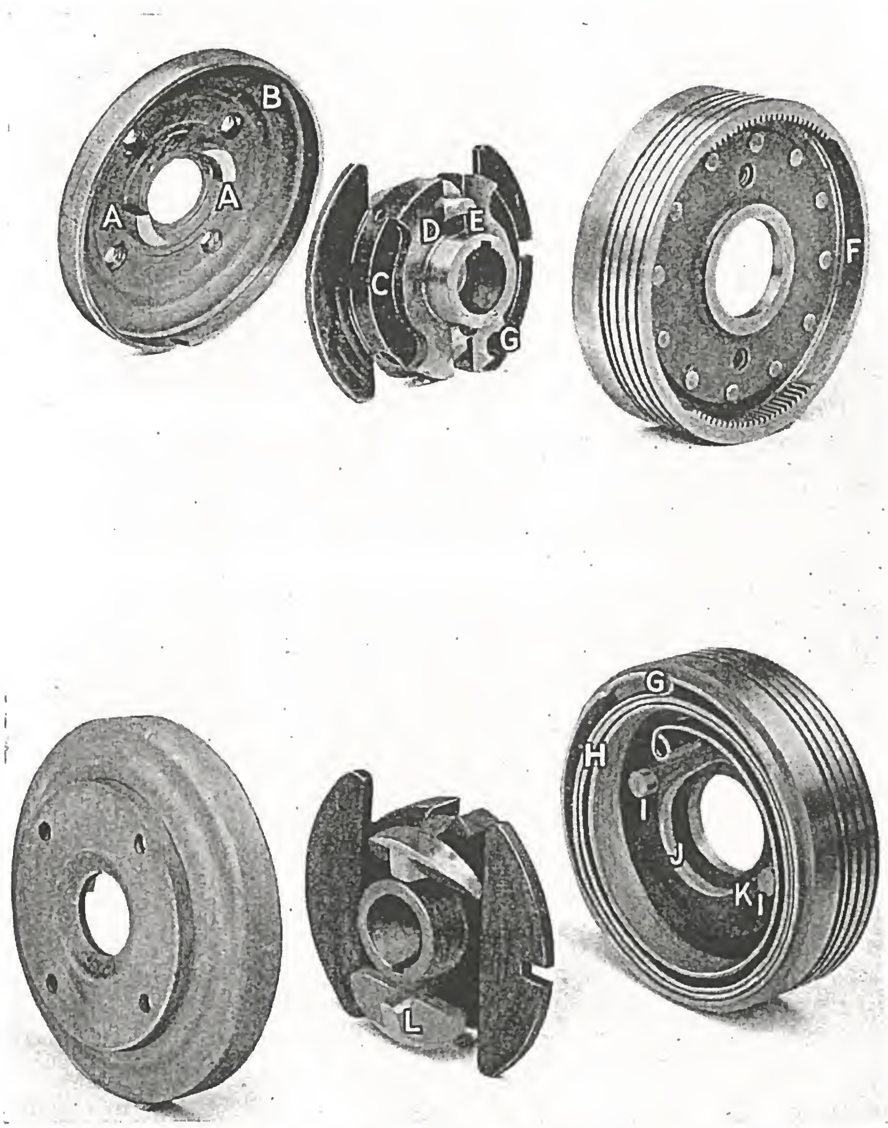


PLATE XVIII. FRONT AND REAR VIEWS OF B.T.H. IMPULSE STARTER

A = Stops which engage with *E*.
B = End plate.
C = Slots in which stops I operate.
D = Hub assembly.
E = End of pawl.
F = Driving member.
G = Anchorage for ends of spring.
H = Clock spring.
I = Stop restricting annular movement of hub assembly.
J = Internal cam.
K = Cam lobe.
L = Weighted end of pawl.

instrument by a vertical central tube. On either side of this lower chamber calibrated orifices are provided through which the fuel flow is controlled. Leading upwards from either side of the body two vertical glass tubes, open to the atmosphere at the top, are fitted. Adjustable scales, graduated to read in pints per hour, are mounted adjacent to the glass tubes. Cocks are fitted below each glass tube through which the supply of fuel is taken direct to the carburettors. When the cocks are closed, the fuel level in the glass tubes is the same as that in the float chamber. When they are open and the engine is running, the level of the fuel in the glass tubes registers the amount of fuel that is being consumed by the engine.

Periodical checks of the flowmeter are made by disconnecting the pipe leading to the carburettor, and checking the free flow by means of a stop watch and measuring vessel and comparing it with the scale reading. This should be done at several positions of the scale by restricting the fuel flow.

All observed b.h.p. figures must be corrected for variation of barometric pressure and air intake temperature. When exhaust manifolds are fitted there is a correction for back pressure in favour of the engine. Details of these corrections are given in paragraph 16 of Design Leaflet C1.

It will be found that an engine is usually given two b.h.p. ratings in the Type Certificate. The higher one is the rated power of the engine and the lower one the minimum power at which subsequent engines of the type may be accepted. The schedule of tests governing the acceptance of new and overhauled engines is detailed in paragraphs 46 to 52 of Design Leaflet C3, and it will be seen that under certain conditions it is unnecessary to test engines on a dynamometer. For this reason a ground engineer who had had no prior bench testing experience would have his licence restricted to the testing of engines with a test fan, or airscrew.

Testing with Airscrews

The use of a flight airscrew for prolonged engine running, on a fixed test bench, or in the machine, is unsatisfactory from the point of view of cooling the engine. Furthermore, the desired load at normal engine revolutions per minute cannot be obtained except by trimming the airscrew. For routine testing, therefore, a calibrated test fan is normally used which is designed to absorb approximately nine-tenths of the rated power of the engine at normal revolutions per minute. On opening up the engine to full throttle the revolutions per minute would increase by about 5 per cent, and it should be possible to establish this figure for each fan for a particular type of engine. Test fans, unless properly designed, are liable to permit an engine to overheat as a result of insufficient air speed and distribution. The test plant should be designed to give an effective air stream to sparking plugs and cylinder heads of air-cooled radial engines of not less than 85 miles per hour.

It should be remembered that power absorption figures of a test

fan, calibrated on a spinning plant, may vary from those obtained on an engine, and two sets of figures may be seen on some drawings.

Airscrew and test fan calibrations should never be used for quoting engine performances, as they must necessarily be only approximate, and even with careful storage when not in use climatic conditions may easily affect their characteristics. The environments of the test bed, and, in the case of open test houses, the effect of prevailing winds might also have a marked effect on their accuracy. Squally weather may affect the speed as much as 200 revolutions per minute. Wind blowing in the direction of the slipstream will tend to make the fan light.

Over-revving can also be produced by a change in design of exhaust manifold.

There is a growing tendency to use airscrew hubs incorporating an oscillation damper, and where such a device is standardized for a particular type of engine it must be considered as an integral part of the engine, and all testing, either with an airscrew, or on a dynamometer, must be done with a similar device fitted.

When testing supercharged engines with a test fan, the characteristics of which have already been ascertained on an engine known to be giving full power, the revolutions per minute, fuel consumption, and rated boost should be sufficient indications that the engine is satisfactory. A test fan is normally designed to absorb approximately nine-tenths of the sea-level power (760 mm. and 15° C.) at rated boost and normal revolutions per minute.

The boost gauge and pipe line must be free of air leaks, otherwise over-boosting may be recorded.

When variable pitch airscrews are fitted it is possible to obtain considerably more power from an engine by blade adjustment than when using a test fan designed to absorb nine-tenths power at normal revolutions per minute, and this point should be remembered.

The introduction of the variable or "controllable" pitch airscrew was necessary because with a fixed blade airscrew, whilst it might be correct for maximum speeds and efficient at cruising speeds where the density of the air is reduced, it would be incorrect for ground running and climb, the pitch being too great for the increased air density on or near the ground. By varying the pitch of the blades at will, this difficulty can be overcome and more power and engine revolutions can be obtained for climb.

One such airscrew is the "Hamilton" (2 pitch) made in this country by Messrs. The De Havilland Co., and it is possible for the blades to be set in one of two positions at will. The operation is effected hydraulically, the main engine oil supply being used in conjunction with a three-way valve which controls the oil supply to a jet in the extremity of the hollow airscrew shaft.

A piston is fitted to the end of this shaft and a cylinder, which moves forward due to the oil pressure, forms the front of the airscrew hub.

The blades are brought into the fine pitch position (for take-off and climb) as the cylinder is forced to its maximum outward position.

On cutting off the oil supply, the blades take up positions corresponding to the coarse pitch (for cruising) due to counter-balance weights (one on each blade) acting under centrifugal force, and which are also sufficient to overcome the natural tendency of the blades when rotating, to revert back to fine pitch positions. The minimum oil pressure required to operate the airscrew blades is determined for each engine during the Type Test and is declared by the makers of the engine. The base setting of the blade angles is controlled by the position of the counter-weight bracket, on which a datum line is marked.

The adjusting stops for the high and low pitch blade settings, which are adjustable independently, are incorporated inside each of the counter-balance weights. All blades must be adjusted to exactly similar settings to prevent cylinder wear.

The range of blade angle movement is normally 10°, but sometimes 20°. The failure of the mechanism to operate may be due to—

(i) A blocked oil system due to presence of carbon or other causes.
(ii) Failure of booster pump, if fitted, or main engine oil supply.
(iii) Wrong balance weights.

Constant speed V.P. airscrews are operated in conjunction with an engine-driven governor which controls the oil supply operating the blades. A booster pump may also be incorporated in the unit. The load imposed by the governor spring can be adjusted by a rack and pinion mechanism or other means, and an extension to the rack is utilized to provide a remote control enabling the airscrew to run at any predetermined speed.

Hunting, oil pressure surge, overrun, etc., may occur when suddenly opening the throttle, but the speed should stabilize itself in a few seconds.

Low oil pressure and temperature will tend to make the change of pitch sluggish.

An engine which functions with a V.P. airscrew should be so tested that the tightness of glands, pipe lines and cocks, associated with the operation of the airscrew, are also checked. In the absence of an airscrew, a rig should be used for the purpose. This requirement is specified in Notice to Aircraft Owners and Ground Engineers, No. 20/1937.

V.P airscrews are treated as complete units and can only be overhauled by ground engineers possessing an "X" licence.

If the test house is situated at an altitude, the power absorbed by a test fan would be less than at sea-level, due to the difference in air density. A fan would be required, designed to accommodate these special conditions. It should be realized that variations in temperature and pressure would necessitate some tolerance or latitude in the acceptance of engines, and figures would be established according to the circumstances.

ENGINE STRIP AND FINAL TEST. During the endurance test, oil and fuel consumptions are taken and a power check is effected at the end of the test. Oil leaks, vibration, irregular running, flat spots, etc., are looked for so that rectifications can be effected prior to the final test.

The extent of stripping to be done will be dependent on the amount and nature of replacements during the overhaul. Inspection will be particularly directed to new and rectified parts and should follow the lines already detailed for the initial inspection.

Prior to the final test the engine should be carefully run up in incremental stages after which final tuning should be effected.

This may include the following—

(i) Adjustment of slow-running jets and throttle stop.

(ii) Check on entry of enrichment jet, if fitted.

(iii) Functioning of mixture control.

(iv) Carburettor flooding at maximum fuel head.

(v) Single ignition check for drop in revolutions per minute. This may vary on each magneto and should not normally exceed 5 per cent.

The final test is a proof run to prove reassembly of parts, but a three-point power curve is often taken if the test is effected on the brake. If the test is done with a calibrated fan, a full throttle reading of the revolutions per minute obtained is recorded.

A final inspection should follow the final test. This would include a check for completeness to the installation drawing and to ensure that pipe unions are tight, nuts are locked and split-pinned, controls are all working freely, etc.

If the engine is likely to be placed in store for some time, cylinders should be sprayed with mineral oil or a rust inhibitor. All orifices should be adequately covered, and external steel parts liable to rust should be treated with a coating of suitable rust preventive.

On completion of the overhaul and test of an engine, a certificate in the prescribed form must be entered in the log book and signed by the ground engineer. Details of the work carried out and the new parts fitted should also be included. The certificate implies that there have been no departures from the type drawings other than subsequent modifications which have been approved.

An entry should also be made detailing all the work carried out, any concessions that have been made, and a list of new parts fitted, together with the release note numbers.

Superchargers

To compensate for the loss of h.p. at altitude resulting from the decrease in density of the air, and resultant lack of oxygen required for properly burning the liquid fuel supplied to the engine, two methods have been adopted to overcome this difficulty—

1. The use of super-compression engines in which high compression ratios are used to obtain an increase in power.

2. The use of a supercharger unit in which the pressure of the mixture in the induction system is raised or "boosted," thus admitting a greater weight of charge into the cylinder on the induction stroke.

Neither of these schemes is in general use on civil engines, although there are a few types embodying one or the other, and the ground engineer wishing to add them to his licence must be fully conversant with the construction, functioning, and testing of these engines. With regard to super-compression engines, there are no special constructional

features—apart from a gated throttle to prevent excessive detonation at take-off speed—which have not already been dealt with, but when we come to the supercharger type we do find some important changes. There are several forms of supercharger units, but for civil aircraft purposes we need consider only the mechanically driven centrifugal supercharger incorporating a rotor between the carburettor and engine. When the rotor is driven at crankshaft speed it is sometimes termed a "paddle fan," and is really a means of obtaining better distribution. When it is driven from four to six times the crankshaft speed it is known as a moderate supercharger, and when it is driven about 12 times the crankshaft speed it becomes a fully supercharged type.

The rotor, turning at anything up to 30,000 revolutions per minute, gives the mixture a high velocity which becomes converted into pressure head as it leaves the tips of the rotor vanes and by this means the induction pressure is raised above that of the surrounding air.

The main limiting factor in supercharging, in order to get maximum power and fuel economy, is the anti-knock value of the fuel. Supercharging raises the temperature and pressure of the mixture entering the cylinders, both of which encourage detonation.

There is a limit to the rated altitude with a single speed supercharger unit and a two-speed rotor would permit the rated altitude to be considerably raised if the correct ratios were selected.

Two-speed superchargers are in use on several types of engine and provide a moderate supercharge up to say 5000 to 6000 feet altitude and a full supercharge up to from 12,000 to 15,000 feet. The take-off and preliminary climb on low gear compared with the high gear, permits a much larger power to be available for the same boost and speed, whilst the high gear with the increased boost is available for the higher altitudes. To take-off on high gear would necessitate a much higher boost pressure to give the same performance, with more risk of detonation due to the greater temperature rise in addition, to increased mechanical loss in driving the rotor at the higher speed. This might be as much as 10–15 per cent, and that for loss of thermal efficiency due to high induction temperature may be nearly as much. The fuel economy on low gear is very great because there are no enrichment jets in operation and the mechanical loss in driving the rotor of the supercharger is not excessive.

The ground engineer must familiarize himself with the details, such as slipping clutches, spring drives, etc., incorporated, in order to avoid risk of failure due to sudden acceleration, deceleration, back-fires, etc.

Slipping clutches usually comprise a number of pads incorporated in one of the driving gears. The pads wedge in an annular groove in the gear wheel under centrifugal loading. If the pads are badly worn there is a possibility that one or more may bottom in the groove. If this occurs, low or fluctuating boost pressures may be expected.

The schedule of tests for the acceptance of normally aspirated engines, Design Leaflet C3 (A.P. 1208), does not cover engines in the supercharger class, which are rated at full throttle at an altitude, and whilst Leaflets C1 and C2 are framed to cover the classification, and the general testing requirements, of both types, the actual schedule of

tests is not provided. Pending the issue of Design Leaflets C4 and C5 for super-compression and supercharged engines respectively, it is usual for constructors to apply the existing service engine schedule in conjunction with Design Leaflet C1 and C2.

Design Leaflet C1 defines the terms the ground engineer must become familiar with in supercharger testing such as rated boost pressure, maximum permissible boost, rated altitude, sea level power, gated throttle power, and full throttle power.

The Service Schedule is known as A.P. 840. Paragraph 6 of Addendum A, deals with "subsequent" supercharged engines, and Addendum B deals with super-compression engines.

The ground engineer who is familiar with the testing of normally aspirated engines should be able to carry out most of the testing required in part 6 of the supercharger schedule, but it is thought that the sequence of corrections necessary in order to arrive at the "corrected" rated power might present some difficulty, and the following notes may be of assistance.

To Ascertain Engine Performance at Ground Level and at a Specific Altitude

The admission of air to the air intake of the carburettor must be controlled in order to maintain a pressure equivalent to the atmospheric pressure at the altitude at which it is desired to run the engine. It is under this condition that observations will be taken in order that the performance of the engine can be eventually established. The data to be observed are: Air intake depression. Air intake temperature. Induction pipe pressure or boost pressure, and b.h.p.

Standard air temperatures at the various altitudes are assumed, and that corresponding to the particular altitude is used in the calculation for ascertaining the "corrected" compression ratio of the supercharger or blower unit fitted.

In order, then, that the pressure corresponding to a particular altitude can be maintained at sea-level test bed conditions, a steel box having two openings is used. From one of these a large pipe leads to the air intake of the carburettor, the other being open to the atmosphere. An adjustable slide or valve is fitted inside the box between these two openings, so that the amount of air admitted to the carburettor can be controlled. A small pipe is connected at a point between the valve and the air intake of the carburettor, which communicates with a Mercury U tube. A shuttered hole for the periodical insertion of a thermometer is also provided.

In order to maintain the desired altitude pressure in the box, the barometer reading of the day is ascertained and the corresponding barometric pressure at altitude subtracted from it. The "difference" is the "depression," which must be recorded on the U tube when the engine is running at normal revolutions per minute at full throttle and power, with the control valve of the box suitably adjusted.

It is to be noted that the area of both orifices, and the pipe leading to the air intake should be such that, when the control valve is fully

open, no depression will exist at the air intake. This will enable an engine to be run at ground level atmospheric pressure without the necessity of removing the control box.

Correction of the Compression Ratio of the Supercharger. The compression ratio of the blower or supercharger would be increased if the air intake temperature was reduced, which is the case when running at altitude, but as the engine is being tested at ground level with the air intake restricted to a predetermined altitude pressure, it follows that the air entering the intake will be at a higher temperature than that at the altitude concerned. The observed ground level air temperature in conjunction with the air temperature at altitude enables the required "correction" to be made.

Rated Boost Pressure. In order to obtain the actual boost pressure at altitude it is necessary to correct the observed boost pressure. This is necessary as a result of the increased compression ratio of the supercharger under altitude conditions as explained in the previous paragraph.

Correction of Observed h.p. for Rated Boost Pressure. The b.h.p. is assumed to vary directly with the absolute pressure in the induction pipe. It is apparent, therefore, that a correction is necessary as a result of the increased compression ratio of the supercharger at altitude, as against the observed or ground level reading. This correction is proportional to the corrected absolute pressure in the induction pipe divided by the "observed" absolute pressure.

Ground Level Power. In the preceding paragraph we have established the b.h.p. of the engine when running at the observed sea-level temperature, but boost as at rated altitude. We now want to find the b.h.p. which the engine will develop at the same rated boost pressure, but with the air intake corrected to a standard temperature of 15° C.

All powers are corrected for air intake temperatures to the square root of the absolute temperatures, and the b.h.p. multiplied by a correction factor will give the ground level power, and it is to be remembered that endurance tests are run at nine-tenths of the ground level power.

Correction of Ground Level Power for Air Intake Temperatures at the Rated Altitude. If this correction is to be accurate, the temperature of the mixture or charge in the induction pipe should be ascertained. This is difficult to carry out because engines are not usually provided with a means of observing this temperature. The rise in temperature due to supercharging is, therefore, ignored, and the air intake temperature is used.

Correction of b.h.p. for Difference in "Charge" and "Exhaust" Pressure at Altitude. This correction is necessary owing to the reduced atmospheric pressure at altitude which provides a lower pressure for the burnt gases to exhaust into. In other words, the "back pressure" on the pistons will be less at altitude than at sea level, and the power of the engine would, therefore, be slightly greater. A formula is given in the schedule of tests to establish the corrected b.h.p. This will give the rated full power at rated altitude at rated boost.

The following example is included to indicate the applications of

the formulae and tables forming part of the Schedule of Tests in A.P. 840, Appendix "A."

Assumed Rating of an Engine—

310 b.h.p. at 3500 r.p.m. at 7000 ft. altitude.
Rated boost $+ 1\frac{1}{4}$ lb. (+ 2.5 in. Hg.).

Observed Data—

Brake h.p.: 280.
Air intake temperature: 25° C.
Barometer on the day: 29·5 in. Hg.
Air intake depression: – 6·41 in. Hg. (adjusted).
Pressure in induction pipe: + 2 in. Hg.

The following symbols are used in the formulae—

p_o = Observed pressure in the induction pipe (absolute).
p_l = Observed pressure in the air intake (absolute).
p_c = Corrected pressure in the induction pipe at altitude Z.
p_z = Air intake pressure at altitude Z.
t_o = Observed temperature at air intake (° C.).
t_z = Air intake temperature at altitude Z (° C.).
(From Table A at 7000 ft. $p_z = 23{\cdot}09$; $t_z = +\ 1{\cdot}14°$ C.).

Correction for Compression Ratio of the Blower—

Observed compression ratio—

$$\begin{aligned} r_o &= \frac{p_o}{p_l} \\ &= \frac{(29{\cdot}5 + 2)}{(29{\cdot}5 - 6{\cdot}41)} \\ &= \frac{31{\cdot}5}{23{\cdot}09} \\ &= 1{\cdot}365 \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(i)} \end{aligned}$$

Corrected compression ratio—

$$\begin{aligned} r_z &= \frac{p_c}{p_z} \\ &= r_o\,[1 + 0{\cdot}00063\,(r_o)^2\,(t_o - t_z)] \\ &= 1{\cdot}365\,[1 + 0{\cdot}00063\,(1{\cdot}365)^2\,(25 - 1{\cdot}14)] \\ &= 1{\cdot}404 \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(ii)} \end{aligned}$$

Correction to Obtain Rated Boost Pressure—

$p_z = p_l$ and $r_z = \dfrac{p_c}{p_z}$

$$\begin{aligned} \therefore p_c &= r_z \times p_z \\ &= 1{\cdot}404 \times 23{\cdot}09 \\ &= 32{\cdot}42 \text{ in. or } (32{\cdot}42 - 29{\cdot}92) \\ &= +\ 2{\cdot}5 \text{ in. Hg.} \quad . \quad . \quad . \quad . \quad \text{(iii)} \end{aligned}$$

CORRECTION OF OBSERVED POWER FOR RATED BOOST PRESSURE—

$$\text{Corrected b.h.p.} = \text{b.h.p.} \times \frac{r_z}{r_o}$$

$$= 280 \times \frac{1{\cdot}404}{1{\cdot}365}$$

$$= 288 \text{ (approx.)} \quad . \quad . \quad . \quad . \quad \text{(iv)}$$

THEORETICAL GROUND LEVEL POWER—

$$\text{G.L. Power} = \text{b.h.p. (corrected)} \times \sqrt{\frac{273 + t_o}{273 + 15}}$$

$$= 288 \times 1{\cdot}0174$$

$$= 293 \text{ (approx.)} \quad . \quad . \quad . \quad . \quad \text{(v)}$$

($t_o = 25°$ C. and Table C gives factor 1·0174 for this temperature.)

CORRECTION FOR AIR INTAKE TEMPERATURE AT 7000 ft. ALTITUDE—

$$\text{b.h.p.} = \text{G.L. power} \times \sqrt{\frac{273 + 15}{273 + t_z}}$$

$$= 293 \times 1{\cdot}025$$

$$= 300 \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(vi)}$$

($t_z = + 1{\cdot}14°$ C. and Table A gives factor 1·025 for this temperature).

CORRECTION FOR EXHAUST BACK PRESSURE AT 7000 ft. ALTITUDE—

$$\text{Factor for rated full power at 7000 ft.} = \frac{100 + \dfrac{(760 - p_z\ m/m.)}{35}}{100}$$

$$\text{or from Table A} = 1{\cdot}050$$

$$\text{Rated full power} = 300 \times 1{\cdot}050$$

$$= 315 \quad . \quad . \quad . \quad . \quad . \quad \text{(vii)}$$

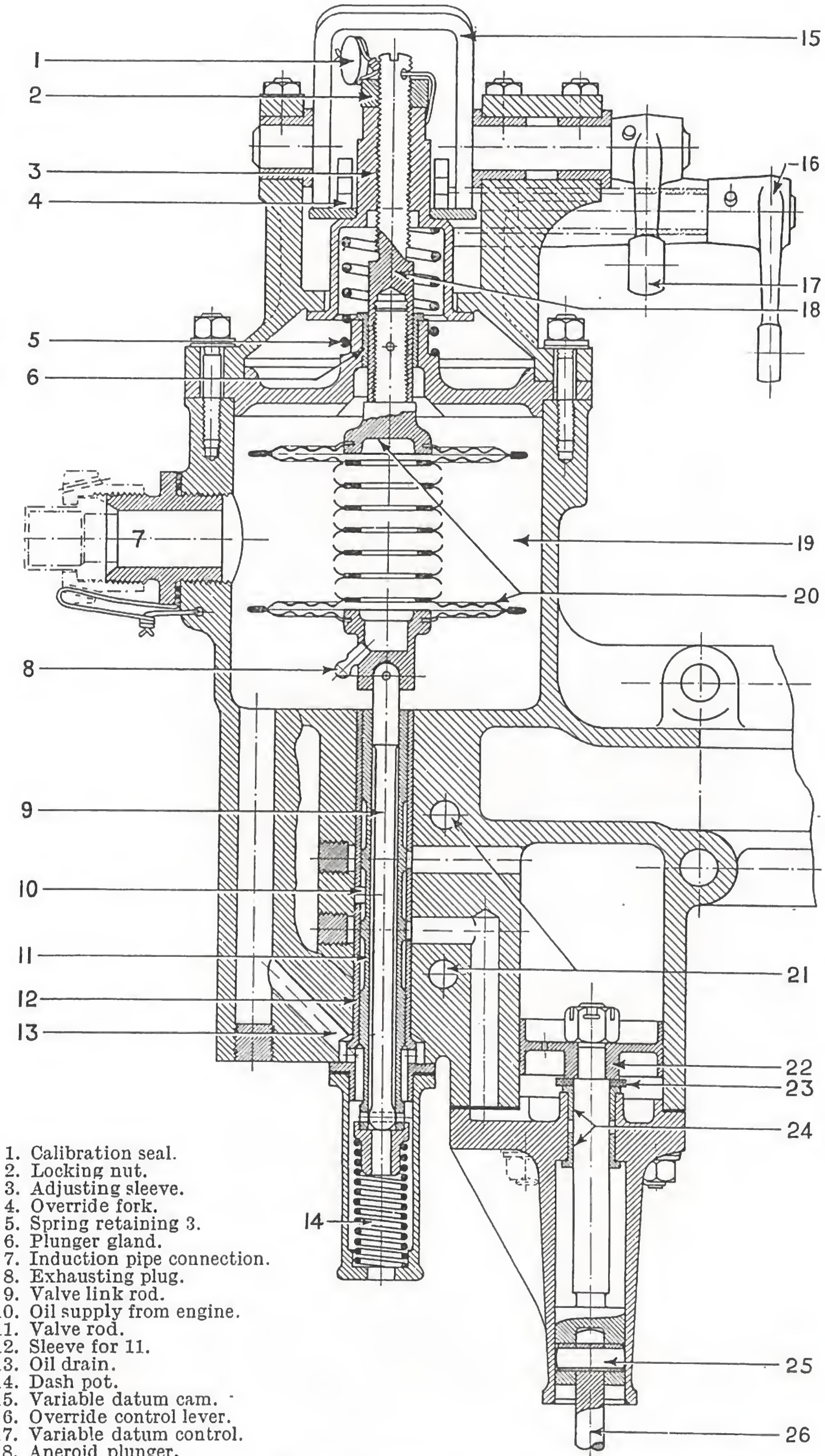
Boost Controls

If an engine is fitted with an automatic boost control a knowledge of the principle, construction, functioning, and adjustment is required. A few notes on these points may, therefore, be of assistance.

OBJECT OF THE BOOST CONTROL. When running an engine at sea level up to rated altitude the rated boost pressure cannot be exceeded even though the throttle lever is fully opened.

CONSTRUCTION. A large sealed cylinder, or chamber, fitted with a union for a pipe connection to the induction casing, contains an aneroid comprising 8 exhausted capsules. One end of the aneroid is connected to a piston valve, the other end has a screwed rod attached to it which protrudes through the end cover of the chamber. The screwing in or out of this rod constitutes the aneroid adjustment, which, when established, is locked by a second nut.

The other end cover of the chamber, through which passes the valve shaft, incorporates a piston valve sleeve which, by means of transfer ports and passages, admits oil from the main engine system



1. Calibration seal.
2. Locking nut.
3. Adjusting sleeve.
4. Override fork.
5. Spring retaining 3.
6. Plunger gland.
7. Induction pipe connection.
8. Exhausting plug.
9. Valve link rod.
10. Oil supply from engine.
11. Valve rod.
12. Sleeve for 11.
13. Oil drain.
14. Dash pot.
15. Variable datum cam.
16. Override control lever.
17. Variable datum control.
18. Aneroid plunger.
19. Aneroid chamber.
20. Aneroid.
21. Scavenge oil ports.
22. Servo piston.
23. Minimum power stop washer.
24. Bush for oil gland.
25. Crosshead.
26. Rod to toggle link.

By courtesy of H. M. Hobson, Ltd.

FIG. 9. VARIABLE DATUM BOOST CONTROL

to the top or bottom side of a piston fitted to a small cylinder, as required. waste oil is conducted to the scavenge system of the engine.

A small hole is drilled in the piston crown to allow a permanent oil leak to prevent a possibility of freezing at high altitudes. The quantity of oil lost is negligible in comparison with the normal flow through the transfer ports.

The piston valve is provided with a spring-loaded dash pot to prevent valve oscillation.

A connecting rod attached to the piston passes through a gland, and is then connected through suitable toggle mechanism to the throttle control shaft on the carburettor.

FUNCTIONING. As the aneroid chamber is connected to the induction casing, the pressure in both will always be the same. Therefore, when any change in boost pressure occurs, the aneroid will expand or contract according to whether the pressure is negative or positive. Any movement of the free end of the aneroid moves the piston valve a corresponding amount, so controlling the flow of oil either to the top or bottom of the piston in the cylinder. The oil from the negative pressure side of the piston passing through an outlet port uncovered by the piston valve.

The toggle mechanism permits the throttle lever to go to the full open position at ground level without the possibility of the permissible boost being exceeded. As the rated altitude is approached the link rod is gradually straightened out by the operation of the piston, until at the rated altitude the pilot's throttle control will still be in the full open position, but the carburettor throttle will be full open also.

MINIMUM POWER STOP. In order to safeguard the pilot in the event of a failure of the boost control unit, or the oil supply to the unit, provision is made to ensure that there is sufficient power available for this eventuality.

This is done in various ways on different units. In one type a washer is inserted under the piston to limit the downward travel so as to give a predetermined power when the throttle lever is full open. This power is normally just below rated boost at standard atmospheric pressure.

It should be noted that washers are not interchangeable between one engine and another.

In another type of boost control a peg is fitted to the piston crown or cylinder head to limit the upward movement of the piston. This must be adjusted for each engine, and if it is too long it may easily affect the initial setting of the aneroid.

ADJUSTMENT. This should be made when the engine is warm. The throttle should be gradually opened until a pressure slightly in excess of the desired rated boost is obtained, and then kept in this position. The aneroid should then be adjusted until the rated boost pressure required is recorded on the gauge, when the adjuster is locked. It will be found that one-sixth of a turn is equivalent to about $\frac{1}{4}$ lb.

A check can be made of the adjustment by easing back the throttle lever and again opening up. If the setting is correct, the throttle lever can be opened to full travel, the boost control having charge of the throttle, so preventing a pressure rise in excess of rated boost.

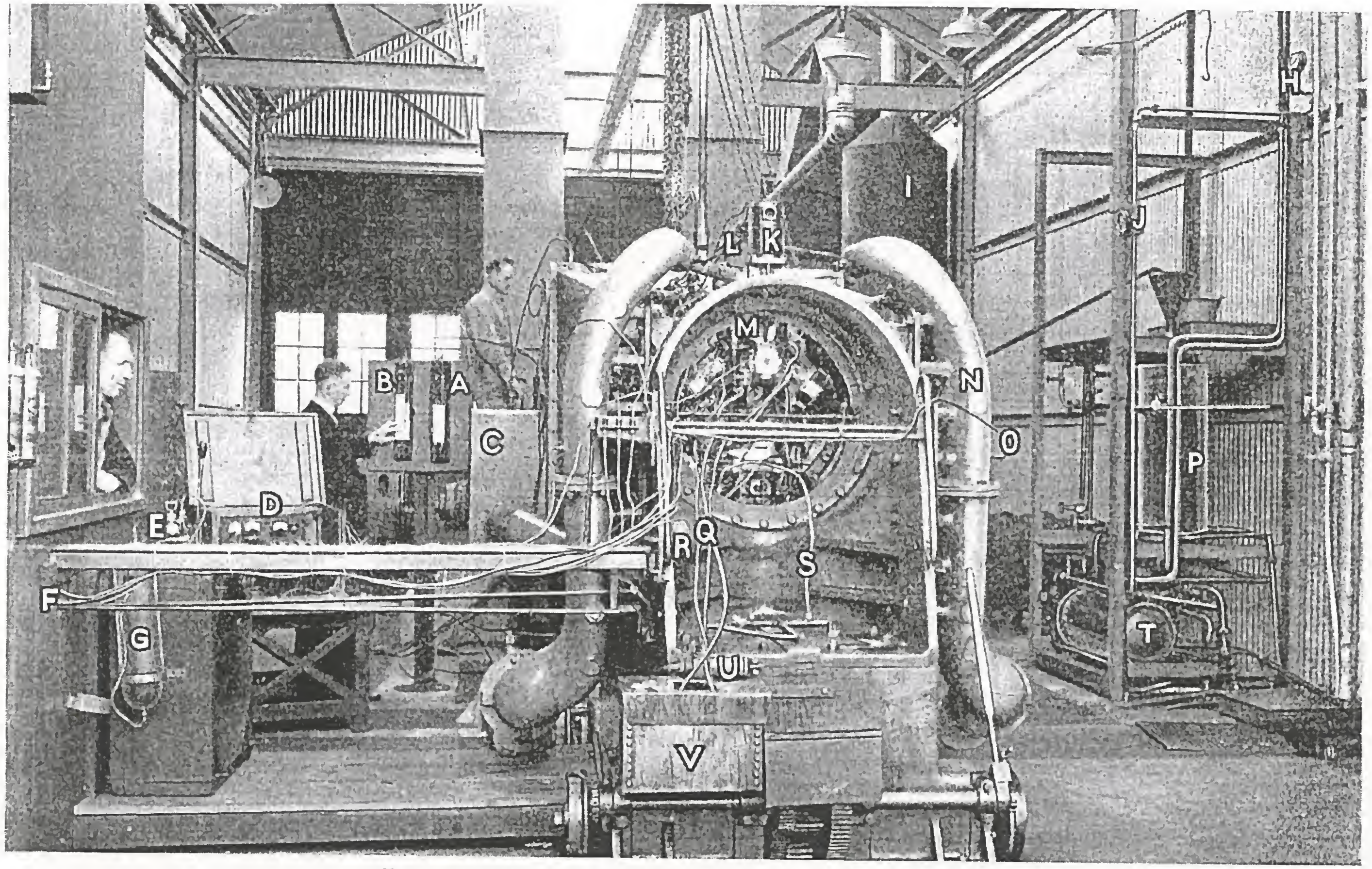


PLATE XIXA. TIGER ENGINE ON TEST (Rear view)

A = Mercury column (Boost pressure).
B = Mercury column (air intake depression).
C = Depression box.
D = Voltmeter and ammeter for generator.
E = Viet hand starter and compressor.
F = Leads from couples in cylinder heads.
G = Compressed air bottle.
H = Pressure of steam to oil tank.
I = Expansion chamber for exhaust gases.
J = Thermometer for oil inlet temperature.
K = Engine-driven generator.
L = Tube supplying cooling air to generator.
M = Engine-driven compressor.
N = Exhaust collector.
O = Tapping for measuring back-pressure.
P = Steam-heated oil tank.
Q = Pipes to and from fuel pumps.
R = Primer pump.
S = Fuel feed pipe from flow meter.
T = Oil cooler.
U = Test bench fuel filter.
V = Petrol tank for fuel pump circulation.

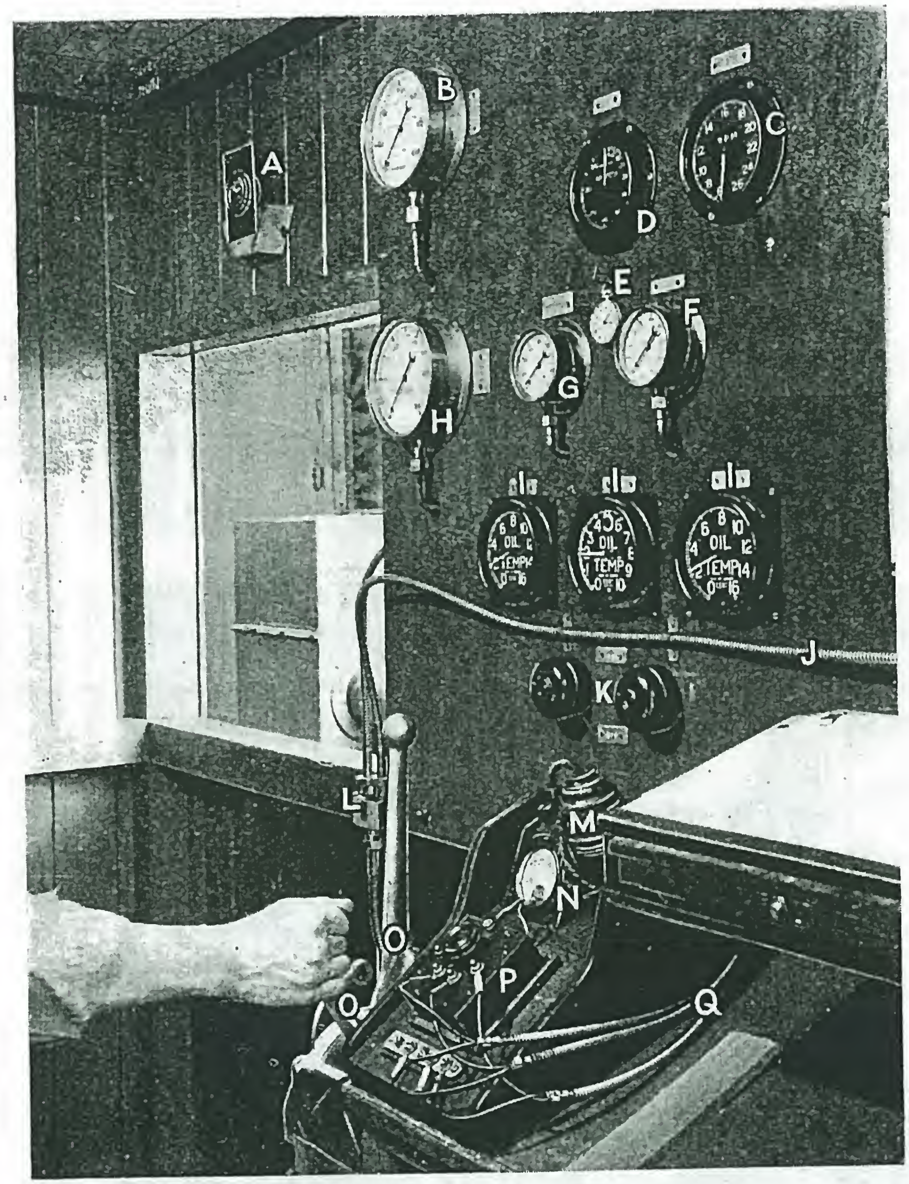
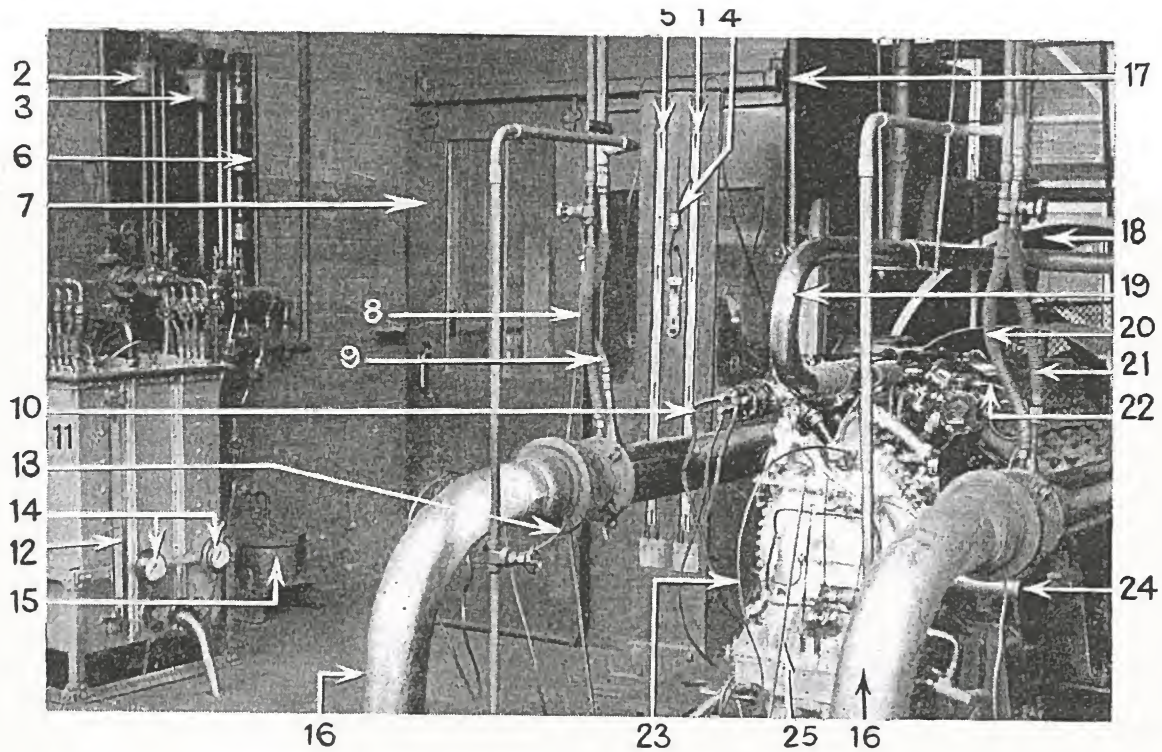


PLATE XIXB. ENGINE TEST BENCH CONTROL CABIN

A = Pressure gauge for petrol pump.
B = Oil scavenge pressure gauge.
C = R.P.M. indicator.
D = Air speed indicator.
E = Watch.
F = Main oil pressure gauge.
G = Crankcase oil pressure gauge.
H = Air compressor gauge.
I = Transmitting type oil thermometers.
J = Flexible drive for Hasler.
K = Engine switches.
L = Tachometer two-way box.
M = Cold junction for thermo couples.
N = Galvanometer for recording temperatures.
O = Engine controls.
P = Thermo couple distribution box.
Q = Thermo couple leads.



By courtesy of *Messrs. Rolls Royce Ltd.*

PLATE XIXc. MERLIN ENGINE ON TEST

The coolant tank and depression box are at the back of the plant.

1. Boost U tube.
2. Flowmeter (small).
3. Flowmeter (large).
4. Silencer back pressure U tube.
5. Air intake depression U tube.
6. Check flowmeter.
7. Control cabin.
8. Water spray into exhaust pipe.
9. Water pipe for silencer cooling.
10. Pipe from R.A.E. compressor to pressure gauge in cabin.
11. Oil tank.
12. Oil gauge (direct reading).
13. Pipe to silencer (back pressure).
14. Vacuum gauges.
15. Float chamber (representing aircraft tank).
16. Water jacketed exhaust pipes.
17. Water pipe for silencer cooling.
18. Tunnel for cooling fan.
19. Coolant pipe (engine cooling).
20. Water spray into exhaust pipe.
21. Water pipe for silencer cooling.
22. Pipe from B.T.-H. compressor to pressure gauge in cabin.
23. Pipe to boost U tube.
24. Starting handle bracket.
25. Throttle control (operated from cabin).

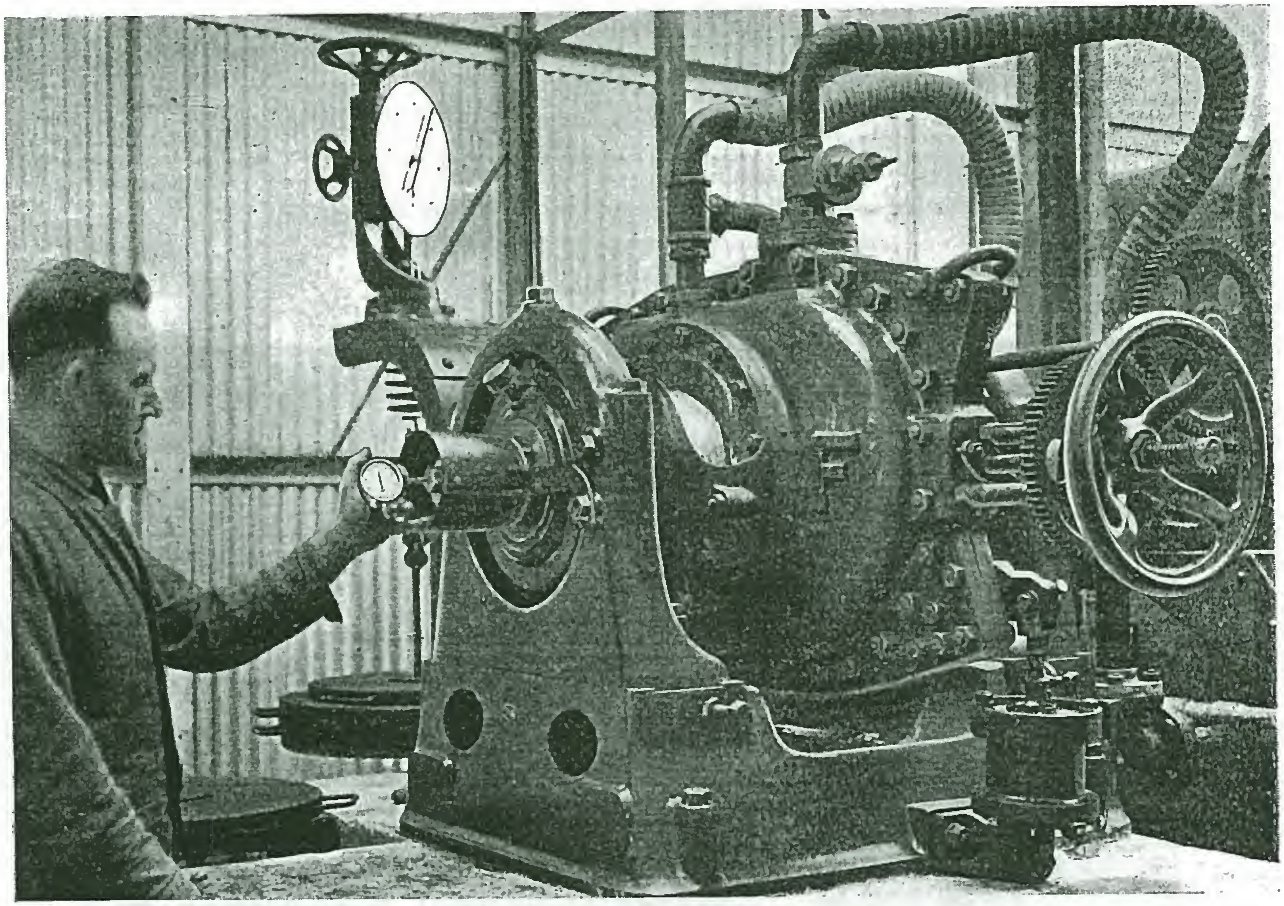


PLATE XIXD. CHECKING ENGINE R.P.M.

The airscrew shaft speed is checked at intervals with a Hasler revolution indicator or similar apparatus. It is sometimes more convenient to check the speed at the end of the brake shaft as in the illustration.

At this boost, the piston takes up a position between its extreme limits of movement and, if oil-operated, may pass as much as 35 gallons of oil an hour, on a high power engine.

Boost Over-ride Control and Enriching Device

Before the present over-ride control was available, some engines were fitted with carburettors incorporating mixture controls set initially weak at the normal rich position. It was then possible to move the mixture control lever through a gate to obtain the normal rich mixture for take-off and throttle openings when the power jet was not in operation.

Object of, and Limitation to, Over-ride. The over-ride mechanism is incorporated in the automatic Boost Control so that maximum permissible boost can be obtained for purposes of "take off" and "climb" if the type engine has been approved to include this. It relieves the pilot of the necessity of watching his boost gauge.

Maximum permissible boost obtained in over-ride varies with the engine revolutions, as it is dependent on the compression ratio of the blower unit, which also varies with engine revolutions.

It should be clear that over-ride is only provided for "take off" and in some cases "climb," and it should not be possible to exceed normal engine r.p.m. in climb other than with a variable pitch airscrew.

With some engines in which the M.P.B. is practically at full throttle at normal engine r.p.m. the carburettor throttle can be fully open without obtaining M.P.B. if the barometric pressure for the day is low. This should not be overlooked when setting the over-ride.

If over-ride is maintained on a climb there may arrive an altitude where loss of power will occur due to over-richness. In such cases, unless an automatic mixture control is incorporated, it may be necessary to revert to the rated boost position of the control which is in effect weakening of the mixture by cutting off the extra fuel provided in override, and referred to later.

Construction. Over-riding or delaying the action of the boost control may be accomplished in three ways—

(i) Mechanically, by providing mechanism to vary the aneroid datum, so causing the pressure to rise in the induction system.

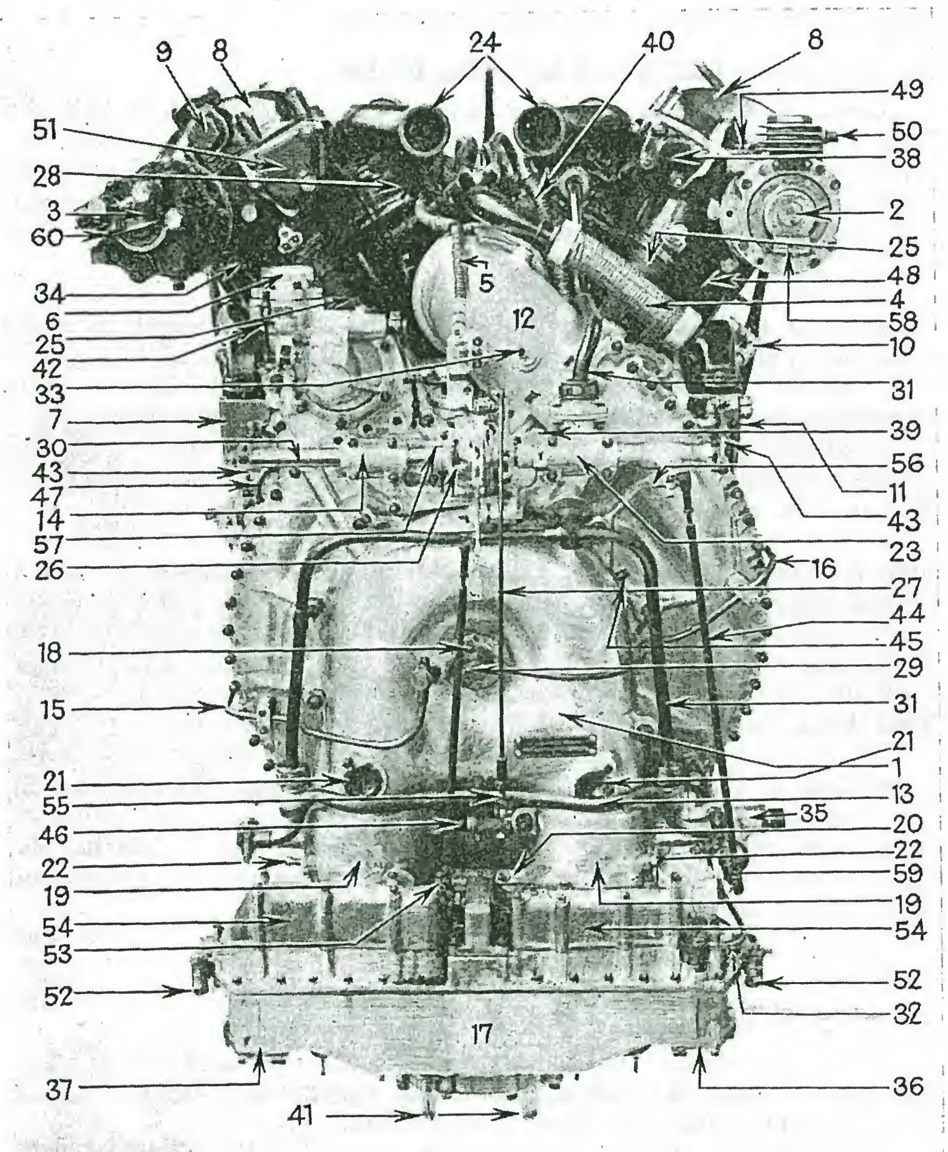
(ii) Some engines obtain maximum permissible boost by passing the throttle lever through a gate, set at rated boost, until it comes to a stop which limits the throttle movement.

If the stop is set to a boost gauge, correction for the barometric pressure of the day must be made. If the stop is set when the engine is on the test bed, a mercury column is used. A trap, however, should be inserted, to protect the engine against mercury being sucked in at small throttle openings.

(iii) By spilling the contents of the aneroid chamber.

In the latter case the pipe from the pressure side of the induction system connects with the aneroid chamber through a calibrated sharp-edged orifice which restricts the quantity of air passing into the chamber.

A venturi is also fitted to a union in the aneroid chamber, and a



By courtesy of *Messrs. Rolls Royce Ltd.*

PLATE XX. ROLLS ROYCE S.U. CARBURETTOR AND MERLIN SUPERCHARGER

Key to Plate XX

1. Supercharger casing.
2. B.T.-H. Compressor.
3. R.A.E. Compressor.
4. Ignition harness.
5. Petroflex priming pipe.
6. Boost control (fixed datum).
7. Magneto (port).
8. Rocker covers.
9. Tachometer drive.
10. Screened sparking plugs.
11. Magneto (starboard).
12. Induction pipe from supercharger.
13. Return oil pipe (throttles to sump).
14. Control shaft bracket.
15. Pipe connecting pressure and suction sides of supercharger.
16. Low pressure oil supply to rotor bearings.
17. Carburettor base.
18. Accelerator pump control rod.
19. Throttle edge jets (slow running).
20. Throttle stop.
21. Core plugs (to facilitate casting).
22. Adjustment for slow running.
23. Control shaft bracket and coolant connection.
24. Coolant pipes (outlet).
25. Camshaft inclined drive.
26. Differential gear (control shaft).
27. Throttle control rod.
28. Induction manifold.
29. Rotor shaft bearing (rear end).
30. Main control shaft.
31. Coolant pipe (choke heating system).
32. Boost pipe to aneroid chamber.
33. Boost gauge connection.
34. Low pressure oil feed pipe to camshaft.
35. Relief valve (throttle heating system).
36. Automatic mixture control aneroid chamber (boost operated).
37. Automatic mixture control aneroid chamber (altitude operated).
38. Spare drive.
39. Stop for throttle in open position.
40. Volute drain (petroflex).
41. Main jets.
42. Emergency cruising control cut out.
43. Magneto control (connected with throttle).
44. Economical cruising control rod.
45. Taper plug (blind flying attachment).
46. Butterfly shaft and glands.
47. Pipe from supercharger to boost control.
48. Low pressure oil feed pipe to camshaft.
49. Air inlet to compressor.
50. Air outlet to bottle.
51. Spare drive.
52. Drain cock (choke heating system).
53. Accelerator pump control adjustment.
54. Variable jet link mechanism cover.
55. Throttle control rod adjustment.
56. Cockpit control connection to 44.
57. Cockpit control connection to 30.
58. B.T.-H. Compressor oil level valve.
59. Economical cruising control rod adjustment.
60. Oil pipe connection from filter.

pipe from this passes to a valve and thence to the suction side of the supercharger.

This valve is opened when over-ride is brought in and for this purpose the mixture control lever is arranged to pass through a gate backwards beyond the full rich position.

FUNCTIONING. When the valve is closed the boost control functions normally. When the valve is opened the pressure acting on the capsules is relieved a predetermined amount owing to the fact that the venturi, being larger than the calibrated orifice, tends to spill more air from the chamber than is entering into it via the calibrated orifice. This allows the aneroid to extend and, via the servo motor and links, open the throttle more and more to give a higher power. The boost continues to rise until equilibrium is maintained in the aneroid chamber.

When the over-ride is in operation it is not possible to use the mixture control, but in order to safeguard the engine against possible detonation a rich mixture is provided by means of an additional supply of fuel. This is done by a separate aluminium casting containing a spring loaded piston valve and a metering jet. It comes into operation at the same time as the over-ride, and provides an increase in mixture strength of about 12 per cent.

VARIABLE DATUM BOOST CONTROL. When closing the throttle from rated boost the pilot's lever would start to move backwards, each movement of the pilot's lever would close the throttle, which would reduce the boost pressure in the aneroid chamber, which, in its turn, would extend the capsules and thereby expose the appropriate side of the piston to oil pressure. The movement of the piston alters the angle and thereby the length of the toggle links and so opens the throttle again. This would continue until the piston had reached the other end of its stroke and the toggle links between the pilot's lever and the carburettor throttle were at their maximum length, following which the pilot's lever would then pull directly on the throttle and close it. This period during which the throttle remains steady in spite of the closing of the pilot's lever is what is known as the "dead" period in the Boost Control and it has been eliminated with the introduction of the variable datum boost control.

If the control is set with the pilot's lever in full throttle position, by means of the screw adjustment at the end of the capsule spindle, to rated boost, and the pilot's lever pulled slightly back to another position and the screw adjustment re-set to a pressure below rated boost and so on down the scale, each different position of the pilot's lever having another setting of the capsule spindle screw, naturally the boost pressure would be lowered each time this screw was adjusted. This would be varying the datum of the boost control with the pilot's lever opening.

In practice this is accomplished by means of a cam, in contact with the top of the capsule spindle, coupled to the pilot's lever so that when the lever is gradually closed the cam allows the capsules to extend, move bodily away from the servo motor, thus varying the datum and making it necessary for a lower pressure to be exerted on the capsules to let the valve come back and maintain the ports in the closed and

sensitive position. In the normal type of boost control the datum is fixed because after adjusting the screw for the required boost pressure, the end of the capsule spindle is locked in position by a wired nut.

Location of Faults During Engine Running

1. Failure of an engine to start.
2. Ignition.
3. Lubrication.
4. Carburation and distribution.
5. Overheating and/or loss of power.
6. Rough running and vibration.

1. Failure of an Engine to Start. This may be due to any of the following—

(a) *Carburettor Jets or Filters Choked with Dirt, Oil or Water.* In such cases it will be necessary to clean thoroughly the float chamber, pipe lines, and possibly the fuel tanks. Water may be present either in the fuel itself, or may accumulate as a result of condensation from the atmosphere. Dirt may include small particles of shellac used as jointing material, or small flakes of boiled oil from the inside of the float chamber or cored passages left after the doping process normally carried out to safeguard against porosity. Oil may accumulate when fuel pumps are fitted if serious leakage occurs at the glands, because this oil is conveyed through the relief valve back to the fuel tank.

(b) *Air Locks in Fuel Pipe Lines.* This may be due to leakage at unions, cocks and fitters, or the length and lay-out of pipe lines may be unsatisfactory.

(c) *Incorrect Doping or Priming.* If an incorrect mixture is supplied to the cylinders when doping prior to starting, difficulty may be experienced. This is more likely to happen with a hot engine. A weak mixture may be due to a defective doping pump or choked nipples. A rich mixture may be due to a flooding carburettor. See item (*b*), Section 4. It is better to under-prime, but if the cylinders have been inadvertently over-primed they can be cleared as follows—

(i) Make sure that the hand starter is out of engagement.

(ii) Make sure that the magnetos are earthed.

(iii) If the engine has been running, leave it a few minutes to cool off.

(iv) Turn the airscrew backwards several times with the carburettor throttle full open.

In hot weather the magnetos should be connected each to one of the two brush connections on the hand starter magneto, in order that both sparking plugs in each cylinder can be made to fire.

Do not switch on main magnetos until all cylinders are firing on the hand-starter magneto, if it can be avoided. If the engine tends to fire, do not try and produce a start by sudden opening of the throttle, because the accelerator pump will discharge fuel and may cause a fire in the air intake.

(d) *Faulty Magneto.* See item (*b*), Section 2. In addition the ignition may be timed incorrectly or on the wrong stroke. The timing of magnetos is dealt with on page 69.

The rocker arm of the contact breaker may be stuck on its pivot. This should then be removed, cleaned and replaced.

(*e*) *Failure of the Impulse Starter.* It is not unusual for the toggle mechanism to cease to function if it becomes clogged with oil and dirt. The remedy is to dismantle and thoroughly clean the parts before re-assembly.

(*f*) *Faulty Sparking Plugs.* (See item (*a*), Section 2.) If the engine has been standing for some days it is possible that the sparking plug insulators may become damp owing to condensation; in such cases they should be removed and thoroughly dried.

(*g*) *Earthing Leads or Switches Defective.* This may result in a magneto being intermittently or permanently earthed. The starter magneto may be defective.

(*h*) *Faulty Ignition Leads.* If braided ignition leads become soaked with water—in particular sea-water—they will cease to function satisfactorily. If the leads are crossed or insecurely fitted to the distributor cover, trouble will also be experienced.

(*i*) When an electric starter is used, it is possible that the accumulator may be nearly run down, and the speed of the crankshaft may be insufficient for the engine to start. In cold weather, oil is very much less fluid, and the speed of rotation will be further reduced. It is then advisable to heat the oil beforehand.

(*j*) *Faulty Gas Starter Valve.* When using a gas starter, one or more of the valves in the cylinders may be faulty; or a gas starter pipe may be blocked or cracked. If the gas starter valves are not in regular use there is a tendency for the hole to be entirely blocked up with carbon. It is possible also for carbon to get under the seat of a valve, in which case the leakage of hot gases will soon weaken the spring, when burning of the valve seat must, of necessity, follow. It is important, therefore, to see that these valves are kept in perfect condition.

(*k*) *Incorrect Timing of Ignition.* On some types of engine the failure of the hand-starting mechanism to properly disengage after the engine has been started may result in the auxiliary drive shaft being permanently twisted. In such cases the ignition timing will be affected and severe backfires may occur on subsequent attempts to start the engine.

(*l*) *Loss of Compression,* due to worn or weak gas rings, leaking valves or loose inserts, dirty lubricating oil with no "body" in it.

(*m*) If an electric motor is part of the starter, the brush gear may be worn or there may be an excess of oil.

If a starter battery is used, this may be run down or in a deteriorated condition.

2. Ignition. Faults with an ignition system may be due to any of the following—

(*a*) *Sparking Plugs.* Unsatisfactory functioning of a sparking plug may be caused by—

(i) Faulty, loose, or cracked insulator. With mica insulators, pin holes may be present, also deposits of lead from the fuel may occur. In both cases electrical leakage may result.

(ii) Burnt, oily or dirty electrodes. Burning of the electrodes indicates pre-ignition or severe overheating, whilst dirty electrodes will cause a loss of power and make engine starting more difficult. Burning and oiling up of points may also occur if the wrong type of sparking plug is used.

(iii) Incorrect gap setting. The gap between the points should never be corrected by adjusting the central electrode with the sparking plug assembled. When the gland nut is slacked off the central electrode should be turned round to obtain the correct gap, which will be checked with narrow feelers.

(iv) Leakage between the gland nut and the central electrode.

Note. In each case it will be necessary to dismantle the sparking plug to clean and adjust. On re-assembly test each sparking plug for satisfactory functioning under a pressure of 100 lb. per sq. in.

(*b*) *Magneto*. Unsatisfactory functioning of a magneto may be due to any of the following—

(i) Dirty, damp, or cracked distributor.

(ii) Pitted or worn contacts. This will necessitate either the renewal of parts, or trimming up the surfaces, leaving them smooth and preferably slightly convex. The latter can be done in a lathe. Alternatively, if a file is used it should be a very fine one, and every care should be exercised.

(iii) Bad contact between the primary lead and the contact breaker pillar, or the insulation of the contact breaker may be defective. Dirt can easily be responsible for leakage.

(iv) Sticking of rocker arm, or wear on its pivot, thus preventing satisfactory "make" and "break."

(v) Contact breaker rocker arm spring corrosion, indicating pending failure. This is dealt with in Notice to Aircraft Owners and Ground Engineers No. 26, of 1934, and a protective treatment is indicated.

(vi) Broken carbon brush. This should be renewed after thoroughly cleaning the track. It is undesirable to attempt to rectify the face of a carbon brush.

(vii) Faulty condenser. This is usually indicated by a white deposit on the contacts.

(viii) Weak spark from a magneto. This suggests that the magneto either requires overhauling or the magnets require re-magnetizing.

If storage conditions are such that dampness may be suspected, the magnetos should be placed in a warm place and dried off.

(ix) If an impulse starter is incorporated this may fail to operate due to its dirty condition, or as a result of wear of the parts. The questions of lubrication and wear are dealt with in Notices to Aircraft Owners and Ground Engineers, Nos. 27, of 1934 and 10 of 1936.

(*c*) *Ignition Leads*. Unsatisfactory functioning of an engine may be associated with the condition of the ignition leads, and the following points may be mentioned—

(i) A breakdown of the insulation may cause a partial or

complete "short." This may happen if the rubber becomes cracked or perished or the cambric or metal brading deteriorated. Oil and heat have detrimental effects on rubber, and for these reasons the leads should be securely attached so that they are quite clear of parts that become very hot. Severe bends and over-tightening of clips are undesirable, and leads should not be allowed to rub against nuts, sharp edges, etc., or fretting will soon occur as the result of engine running.

(ii) A bad contact or connection in the socket of the distributor cover may cause intermittent firing of the plug in the cylinder corresponding to the faulty lead.

3. Lubrication. Trouble with lubrication may be experienced under any of the following headings—

(a) *Low or Fluctuating Oil Pressure.* This may be due to any of the following causes—

(i) Shortage of oil in the sump or tank.

(ii) Air leaks in the suction pipe to the oil pump. All unions should be tight.

(iii) Relief valve incorrectly set or stuck up due to dirt under its seating.

(iv) Faulty pump. Efficiency of a gear pump will be seriously impaired if the walls have been scored badly with dirt, sand, etc., or if the gear teeth have worn to such an extent that excessive back lash results.

(v) Worn connecting rod bearings. The diametrical clearance and end float of bearings on their crank-pins control, to a great extent, the pressure of the oil, particularly on engines where the capacity of the oil pump is normally only just sufficient for the engine.

(vi) Leaking crankpin plugs. This trouble is not uncommon, and can only be prevented by carefully lapping in all plugs at engine overhaul followed by an appropriate pressure test.

(vii) Defective pressure gauge or possibly a blockage in the pipe leading to the gauge. In cold weather the oil in the pipe may become rather thick, and as a result the true pressure will not at first be recorded. Further delay may occur if the pump and system have not been primed.

(b) *High Oil Pressure.* This may be due to any of the following causes—

(i) The relief valve may be sticking due to dirt. If an auxiliary relief valve is fitted inside the crankcase and functioning does not occur regularly, there is a risk of the valve becoming blocked due to congealed oil.

(ii) The relief valve may be adjusted incorrectly. If a spring of incorrect length or gauge of wire is fitted the blow-off pressure will be incorrect.

(iii) The pressure filter may be choked with dirt and carbon.

(iv) The pressure gauge may be defective. It will be appreciated that when starting up an engine, the oil will be cold and sluggish, and pressures recorded will be higher than when the oil is hot.

(c) *High Oil Consumption.* This may be due to any of the following—

(i) Oil passing piston and scraper rings due to excessive gaps or unsatisfactory ring surfaces. It can be detected on the test bench if stub pipes are fitted for the tests, by a careful examination of the exhaust.

(ii) Oil leakage from breathers. This may be due to the breathers not functioning satisfactorily, or to overheating causing an excess of oil mist to leave the breather as a result of increased crankcase pressure.

(iii) Leakage at tappet guides, etc.

(iv) Leakage from spring loaded oil gland on impellor spindle due to faulty bedding of face, weak or broken springs or sticking gland.

(v) High oil temperatures and pressures.

(vi) Faulty scavenging due to leakage on suction side of scavenge pump or faulty pump.

(vii) Leakage from pipe line unions.

(viii) Faulty measuring apparatus, or aeriation of oil, thus giving unreliable measurement.

(d) *Low Oil Consumption.* This may be due to any of the following—

(i) See item (c) (viii) above.

(ii) The oil consumption reading may be misleading if the whole of the oil in circulation is not warmed up. For this reason no reading should be taken for, say, 10 minutes after the engine has run at 9/10ths load.

(iii) With some engines the master rod bearings act to an important extent as oil metering devices, in that if the diametrical clearances and end float are too small, the cylinder walls may not be adequately lubricated, and low oil consumption will be recorded.

Whilst this point should not be overlooked, it should be remembered that it is well to pass engines out with oil consumptions as near as possible to the low limit of the rating.

(e) *Suitability of Oil.* It should be quite clear that brands of oil inferior to, or different from, those approved for a particular type of engine must not be used. Many oils may appear to function satisfactorily during a short run on the test bench, but may be entirely unsuitable for a particular set of conditions over a long period of service in the aircraft. Thus, an oil suitable for cold climates may be quite unsuitable for hot ones, and it is to be expected that high oil consumption, ring gumming and similar troubles, will be experienced if the wrong oil is used.

4. Carburation and Distribution. *Note.* The tuning of an engine should be done when it is warm, and the correctness of the distribution may be checked by the colour of the exhaust flame when running with stub pipes fitted at 9/10ths power. (See page 76 for further particulars.) If the mixture control is gradually opened up and the engine revolutions increase, this is an indication that the mixture was initially too rich; conversely, if the revolutions drop as the mixture control is

opened, an initially weak mixture is indicated. The actual fuel consumption should be checked on a flowmeter.

Flame traps are incorporated in the induction pipes of some engines to obviate any tendency to cut out due to weak mixtures, inlet valve leakage, etc. In addition, atomization of the fuel is also improved.

A flame trap may comprise a pad or roll of corrugated metallic strip which fills the whole of the induction passage.

Unsatisfactory distribution may be due to any of the following—

(*a*) *Choked Carburettor Jets or Filters.* (See item (*a*), Section 1.)

(*b*) *Carburettor Flooding.* Erratic functioning of the float mechanism may easily affect the correctness of the mixture, and the following are contributory causes—

(i) Wear of the needle, needle valve seating or dirt preventing the needle from seating properly. Parts should be renewed if any defect is noted and needles may be lightly lapped into the valve seatings, using metal polish as a lapping medium.

(ii) Pin missing from a toggle, or sticking needle.

(iii) Punctured float, or in the case of a cork float, punctured varnished coating which would permit fuel to enter the cork.

In the case of a metal float it should be immersed in hot water; the fuel will evaporate and the leak can be traced. After all fuel has been expelled the hole can be soldered up.

With cork floats there is a risk of some protective coating being attacked if fuels containing alcohol are used, in which case blisters will appear and peeling commence. The cork is soft on the surface and will eventually become fuel logged. Re-surfacing a cork float is difficult owing to the number of coatings that have to be applied. Special cellulose varnish must be used.

(iv) Level of fuel in float chamber too low. This may result in misfiring or cutting out of the engine on opening up and climb.

Level of fuel in float chamber too high. This can be checked by substituting the base plug for one with a pipe incorporated. A glass tube is connected to this pipe by means of rubber tubing. The level of the fuel in the float chamber when under the stipulated head, usually 6 ft., can then be ascertained. On replacing the base. plug care should be taken to see that same is locked.

(*c*) *Jet Sizes Incorrect.* An examination should also be made for loose or damaged jets and diffusers.

(*d*) *Loss of Compression.* If the compression varies on one or more cylinders trouble may be expected. A method of testing compression where it is not convenient to try each cylinder in turn by turning the airscrew has been adopted by some operating companies, and is carried out as follows—

A sparking plug body is fitted with a piece of copper tubing, the end of which is bell-mouthed to accommodate an ordinary cork. This is fitted to each cylinder in turn, one plug in the other cylinders being removed.

The engine is turned slowly by means of the hand starter, and if the compression is satisfactory the cork should be forced out. The test should preferably be done whilst the engine is warm. If the cork

remains in position it is probable that any of the following troubles may be present—

Valves not seating satisfactorily.
Gas starter valve leaking.
Piston ring broken or stuck in its groove.
Faulty cylinder head joint.

(e) *Air Leaks*. These are the main cause of weak mixtures, and on certain types of engine can be readily detected by the smoke test referred to on page 76. Leakage of air may occur from any of the induction joints, which should be checked individually for condition and tightness of nuts. Worn inlet valve stems and their guides and particles of grit under the inlet valve seats are also sources of air leakage.

Mixtures of the order of 65 per cent of the correct mixture strength and below will result in the failure of an engine to fire. Weak mixtures result in a slow rate of flame propagation, and the exhaust products are still at a high temperature when the inlet valve opens to admit a fresh charge, the ignition of which causes a flame to pass into the induction system with the familiar "pop back."

(*f*) Carburettors in which the main body comprises two portions, normally incorporate some form of joint. In many carburettors the functioning of the pressure balance and mixture control systems depends on maintaining air pressure or depression above the fuel in the float chamber, and for this reason care must be taken when making this joint to see that the faces are scrupulously clean and free from air leaks.

(*g*) If more than one carburettor is fitted to an engine the throttles, mixture controls, and power jets should be carefully synchronized so that the operations in each carburettor are effected simultaneously. The same remarks apply to carburettors incorporating more than one throttle.

(*h*) If diaphragm petrol pumps are fitted the diaphragms may become split or punctured, in which case recalibration on a rig, after replacement, becomes necessary. Alternatively, if an incorrectly adjusted pump is fitted, flooding of the carburettor may occur. The relief valve spring loading may vary with different installations.

(*i*) If testing is carried out with the air intake in the slip stream from the test fan, propeller, or air flow from the brake fan, the distribution will be upset. Similarly, if the air intake is non-standard, or if flame traps or air filters are incorporated, the results with standard jets may easily be unsatisfactory.

(*j*) Erratic distribution may be caused if the air vent of the filter cap of the tank or the vent pipe are stopped up.

Slow Running. This can easily be affected by most of the causes enumerated in Section 4. In addition, the following points are brought to your notice—

(*a*) The butterfly of the throttle may not close fully, or if more than one throttle is incorporated in a carburettor, they may not be quite synchronized.

(*b*) Slow running jet may be out of adjustment, and where a quantity screw is incorporated this may be set incorrectly.

(*c*) Where face glands are incorporated on impellor spindles to effect a seal between the crankcase and impellor casing, leakage of air might occur due to the gland lifting as the result of suction at slow engine speeds counteracting the spring loading on the gland.

(*d*) *Broken or Weak Valve Springs.* The former must be changed. The latter, if more than one is fitted to a valve, can sometimes be selected as a temporary measure, to give a satisfactory combined loading.

5. OVER-HEATING AND/OR LOSS OF POWER. These conditions may be attributable to any of the following—

(*a*) *Rich and Weak Mixtures.* (See Section 1, items (*a*) to (*c*).)

(*b*) *Detonation.* This may be caused by—

(i) The use of an unsuitable fuel, that is to say one inferior to that approved on the Type Engine.

(ii) The ignition timing advanced too far.

(iii) The compression ratio too high. See page 68 for further particulars.

(*c*) *Pre-ignition.* This may be due to—

(i) Overheated sparking plug points.

(ii) Incandescent carbon on the piston crown and valves.

(iii) Sharp edges, such as a burred screwdriver slot, often provided on the valve head, which may become red hot.

Note. The above can be accelerated by insufficient cylinder cooling due to a faulty airspeed indicator, omission of cylinder baffles, if normally fitted, and excessive oil inlet temperatures.

(*d*) *Ignition Timing.* If the ignition is retarded this will cause overheating, but an advance in the ignition normally permits weaker mixtures to be used.

(*e*) *A Dirty Engine*, that is to say, one that requires top-overhauling or decarbonizing. It may also have weak compression on some cylinders owing to the valve condition, and will certainly be down in power.

(*f*) *Dirty Sparking Plugs.* (See Section 2, item (*a*).) A loss of power will result from dirty sparking plugs.

(*g*) *The Cooling System.* On water-cooled engines the cooling system may be unsatisfactory in regard to the following—

(i) Insufficient radiator surface, or insufficient cooling due to deposits and dirt.

(ii) Water leaks from rubber joints, cocks, pipe lines and pump gland.

(iii) Faulty water pump, due to corrosion, etc., causing loss of efficiency in circulation of the water, particularly at speeds below normal.

(iv) Air leaks in the water system or steam pockets in the cylinders.

(*h*) If the water jackets of cylinders are "furred" up with deposit thrown out of the water, overheating may occur. If such is the case deposit should be removed as already described on page 49. It is always advisable to use distilled or rain-water for cylinder cooling.

(*i*) *Silencing.* Manifolds creating excessive back pressure will cause loss of power and overheating on some cylinders.

(*j*) Airscrew test fans providing an air speed of less than 80 miles an hour are likely to permit an engine to overheat if run for long periods at large throttle openings.

(*k*) With a supercharged engine the failure to get rated boost may be due to a slipping clutch.

(*l*) *Faulty Boost Control—*

(i) Ensure that the oil pipe line to, and the return pipe from, the boost control unit are quite clear of obstruction Failure of the oil. pressure means failure of the boost control, and a stop is provided on the piston as a safeguard.

(ii) The oil hole in the piston of the unit should be clear, otherwise surging may occur.

(iii) All pressure and depression pipes to the unit must have unions tight, and pipes must be free from cracks.

(iv) If a boost gauge is used to measure boost pressures, it should be checked daily against the standard barometer.

(v) A punctured capsule will cause failure of the boost control. Capsules may fail due to rough handling, excessive engine vibration. etc.

(vi) Hunting or variable boost may be due to worn linkage mechanism, worn or slack sleeve controlling piston ports, capsules with incorrect expansion rate under temperature and pressure changes, incorrect leak hole in piston, etc.

A change of pressure of $\frac{1}{8}$ lb. per sq. in. should cause the piston to move, and accuracy within $\pm\frac{1}{8}$ lb. per sq. in. may be expected.

(vii) With air-operated boost controls, grit may score the cylinders and cause fluctuation.

(viii) Tight or dirty piston valves will cause sluggish operation and possibly a low boost reading at rated boost position. The valve should be removed, lapped with metal polish, washed and replaced.

6. Rough Running and/or Vibration. These may be caused by any of the following—

(*a*) See Section 1, items (*b*), (*g*) and (*j*) and Sections 4 and 5.

(*b*) *Dirty or Incorrectly Adjusted Sparking Plug Points.* See Section 2, item (*a*). *Note.* After a run a faulty plug can usually be found, because it will be considerably cooler than the others.

(*c*) *Clearance of Valves.* These may be out of adjustment.

(*d*) *Valves or Tappets Sticking.* This may be due to bent stems in the case of valves, and if over-heating has occurred scaling of the stem may also result in a valve sticking in its guide. After rectification or renewal the valve stem should be smeared with high melting point grease and graphite before fitting.

(*e*) *Broken or Weak Valve Springs.* The former will occur if the spring is not seating flat and square. Similarly springs may give trouble if used on an engine of similar type but later series, because critical speeds may arise which produce "surging," or the engine may be fitted with high lift camshafts which would also impose additional stresses.

Springs are often enamelled different colours to denote class of material or other limiting features.

(*f*) *Excessive Back-lash of Reduction Gear Teeth*, or engine parts out of balance. This latter point becomes particularly important with Rotary Engines.

(*g*) *Faulty Magneto*, or magnetos not properly synchronized. See Section 2, item (*b*). A faulty magneto can be detected by effecting a check on each magneto separately and noting the drop in airscrew revolutions. If the drops exceed those normally noted on the port and starboard magnetos respectively, a faulty ignition system may be expected. If no drop occurs it may be assumed that the ignition timing is advanced too far.

(*h*) *Test Bench*. The following faults may contribute to erratic running—

(i) The engine mounting too flexible.

(ii) The foundations of the test house floating.

(iii) The alignment of the engine with the brake shaft incorrect.

(iv) Hunting may occur due to incorrect adjustment of the dashpot or fluctuating water pressure.

(v) Loose or unsuitable coupling between engine and brake shaft.

(vi) If an airscrew test fan is used it may be out of balance, or the hub may be loose on the airscrew shaft.

Note. When tuning an engine overheating may occur if it is run for some time at large throttle openings, and if suddenly switched off explosions may occur due to the high temperature of sparking plugs, valves, etc. For this reason stopping an engine should be carried out as follows—

(i) Run the engine for a little while at its minimum speed so that engine has time to cool off.

(ii) Turn off fuel and when firing has ceased switch off magnetos.

Compression Ignition Engines

This type of engine has already reached a state of development when it has taken aircraft into the air, and a short time only is likely to elapse before they are in a state of production. It is natural, then, that if a ground engineer wishes to obtain a licence for a compression ignition engine at the present moment, he would be expected to have a thorough knowledge and experience of the particular type. Speaking generally, compression ignition engines differ from petrol engines only in so far as combustion and ignition systems are concerned, the carburettor being superseded by one or more fuel pump units, whilst the magnetos and sparking plugs are dispensed with altogether. The two-stroke principle of engine operation as well as the four-stroke "Otto" cycle will be met with in certain types of compression ignition engine.

When comparing the performance of compression ignition engines with petrol engines, a number of differences will at once be apparent and your attention is drawn to the more important of these.

(i) The C.I. engine has a high thermal efficiency at all loads and consequently there is less heat rejected to the water jackets in the case

of liquid-cooled types, and to the surrounding air in the case of air-cooled types.

(ii) The C.I. engine has a high ratio of maximum to mean cylinder pressure, and the construction is accordingly slightly more robust than the petrol engine.

(iii) The specific fuel consumption is much less than that of a petrol engine and the weight of fuel to be carried for long flights represents a big saving over that for a petrol engine.

(iv) Pure air only is aspirated and if a supercharger is incorporated the same quality of fuel is used. There is more scope for the development of the two-stroke principle when only pure air is drawn into the combustion chamber.

(v) The tendency of the C.I. engine to detonate compared with the supercharged petrol engine, is very much reduced because in the former case the fuel is injected near the end of the compression stroke.

(vi) The fuel used in C.I. engines is much less volatile at low temperatures than petrol and danger from fire is much reduced.

(vii) The absence of electric ignition eliminates one of the main causes of wireless interference.

It will be found that high compression ratios are made use of, and special attention must be given to clearances affecting the combustion chamber. Valves and piston rings must receive careful attention for the same reason.

It will be seen from the foregoing remarks that a ground engineer familiar only with petrol-driven aero-engines, will have to become conversant with the functioning and adjustment of the fuel pumps peculiar to compression ignition engines, and the various atomizers which spray the fuel into the combustion chamber. Normally, the fuel is injected towards the end of the compression stroke, and the charge in the combustion chamber is ignited as the result of the heat generated during the compression stroke. The arrangement for mixing the air and fuel varies according to the type of engine and design of the combustion head.

The fuel pumps measure the amount of fuel, which varies according to the load on the engine, and deliver it at high pressure to the atomizers. The pumps, which constitute part of the engine, are usually of the plunger type. Gear type booster pumps are sometimes fitted to supply fuel from the tank at a pressure to the main pumps, a relief valve being incorporated in the system.

The fuel pumps may be arranged in blocks embodying a number of them, or each pump may be a separate unit, and it should be clear that in either case a pump is required for each cylinder, and a calibration of the fuel delivery from each pump has to be made separately. The pumps are usually controlled as regards the quantity of fuel and period of injection by means of a plunger type control valve. This is very important, as it has a direct bearing on the cylinder pressures obtained during the ignition of the mixture.

The fuel valve, or atomizer, usually comprises a valve with a spring that lifts at a high pressure, normally well in excess of 1000 lb. per sq. in., and allows fuel to pass through one or more small holes into the

combustion chamber. The fuel is specially filtered before passing to the atomizer valve. The valve must be a perfect fit on its seating, and on being tested the fuel should pass at a definite pressure obtained by adjustment of the spring. When the pressure is released the fuel should cut off definitely without dribble. It is important to keep clear of the jets of fuel when testing. There is normally an external leakage of fuel from the atomizer, and this is carried away by a pipe.

The ground engineer will also have to be familiar with any supplementary system which may be embodied to facilitate starting, and it is usual in this connection to incorporate a decompressor which operates on the exhaust valves. In addition provision is normally made to retard the period of injection to prevent excessive cylinder pressures.

It is of the utmost importance that the maximum permissible cylinder pressures shall not be exceeded, and for this reason the normal test bed equipment must be augmented by some form of apparatus for recording cylinder pressures. One such piece of apparatus includes a disc valve unit, an air bottle, and a pressure gauge. A passage from the cylinder to be measured is connected to one side of the disc, whilst a pipe from the air bottle is connected through a regulating valve to the other side. The disc has a limited movement, and when on its seating is insulated electrically from the body of the unit.

The regulating valve from the air bottle is gradually opened until the pressure each side of the disc valve is balanced. When this occurs the disc acts as a "make and break" of a primary electrical circuit, and induces a high potential spark in the secondary circuit. This spark is arranged to jump a gap between the end of the pointer of the pressure gauge, and the outside of its case. Readings should be taken of pressures corresponding to intermittent sparking as well as regular sparking.

It is believed that a schedule of tests for acceptance of compression ignition engines after overhaul is in draft form, and will be issued in due course as Design Leaflet No. C6 (A.P. 1208).

APPENDIX I*

XX. BRINELL HARDNESS NUMBERS AND APPROXIMATE TENSILE STRENGTH OF STEEL

Diameter of Impression in mms.	Brinell Hardness No. 3000 kg. load	Approx. tensile strength tons/sq. in.	Diameter of Impression in mms.	Brinell Hardness No. 3000 kg. load	Approx. tensile strength tons/sq. in.
2·00	946	206·0	4·50	178	40·2
2·05	899	196·0	4·55	174	39·2
2·10	857	187·0	4·60	170	38·3
2·15	816	178·0	4·65	166	37·4
2·20	779	171·0	4·70	163	36·6
2·25	745	162·0	4·75	159	35·8
2·30	712	155·0	4·80	156	35·1
2·35	681	149·0	4·85	152	34·2
2·40	654	142·0	4·90	149	33·8
2·45	626	136·0	4·95	146	33·3
2·50	601	131·0	5·00	142	32·7
2·55	577	126·0	5·05	139	32·0
2·60	555	121·0	5·10	136	31·3
2·65	534	116·1	5·15	134	30·9
2·70	514	112·0	5·20	131	30·2
2·75	495	107·9	5·25	128	29·5
2·80	477	104·8	5·30	126	29·0
2·85	460	100·2	5·35	123	28·4
2·90	444	96·8	5·40	121	27·9
2·95	429	94·0	5·45	118	27·5
3·00	415	91·0	5·50	116	26·5
3·05	401	88·0	5·55	113	26·0
3·10	388	85·2	5·60	111	25·5
3·15	375	82·3	5·65	109	25·0
3·20	363	79·1	5·70	107	24·5
3·25	352	76·8	5·75	105	24·0
3·30	341	74·4	5·80	103	23·5
3·35	331	72·2	5·85	101	23·0
3·40	321	70·0	5·90	99·2	22·75
3·45	311	67·8	5·95	97·3	22·5
3·50	302	65·8	6·00	95·5	22·0
3·55	293	63·0	6·05	93·7	21·5
3·60	285	61·3	6·10	92·0	21·0
3·65	277	59·6	6·15	90·3	20·75
3·70	269	57·8	6·20	88·7	20·5
3·75	262	56·4	6·25	87·1	20·0
3·80	255	54·8	6·30	85·5	19·75
3·85	248	53·4	6·35	84·0	19·25
3·90	241	51·8	6·40	82·4	19·0
3·95	235	51·0	6·45	81·0	18·75
4·00	229	50·8	6·50	79·6	18·25
4·05	223	50·2	6·55	78·2	17·75
4·10	217	48·8	6·60	76·8	17·5
4·15	212	47·7	6·65	75·4	17·5
4·20	206	46·4	6·70	74·1	17·0
4·25	201	45·3	6·75	72·8	16·75
4·30	197	44·2	6·80	71·6	16·5
4·35	192	43·2	6·85	70·4	16·25
4·40	187	42·2	6·90	69·0	16·0
4·45	183	41·2	6·95	68·0	15·75

For 220 and upwards, add 5 to 7·5 per cent for tensile strength if dealing with normalized Carbon steels.

By courtesy of John Brown & Co., Ltd.

* From the *Handbook of Aeronautics*, Vol. I. (Pitman, 25s.)

BRINELL HARDNESS NUMBERS

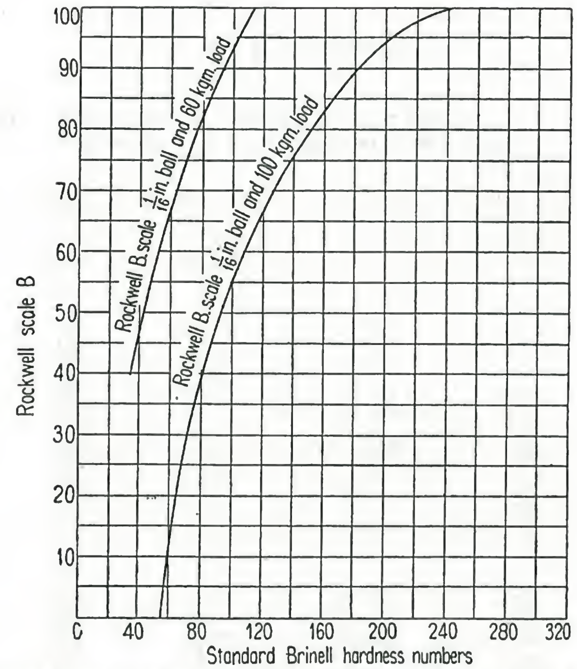


FIG. 1. CONVERSION TO STANDARD BRINELL HARDNESS NUMBERS OF ROCKWELL B SCALES

BRINELL HARDNESS NUMBERS

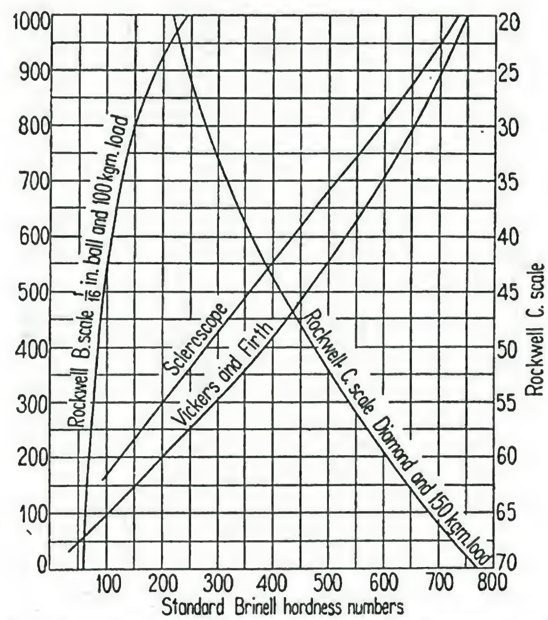


FIG. 2. CONVERSION TO STANDARD BRINELL HARDNESS NUMBERS OF ROCKWELL (C AND B SCALE), VICKERS' AND FIRTH'S DIAMOND HARDNESS NUMBERS AND SCLEROSCOPE

Figs. 1 and 2 from "The Inspection of Metals and their Alloys," by L. W. Johnson, M.C., Met., *The Journal of the Royal Aeronautical Society*, June, 1930.

APPENDIX II

BRIEF DEFINITIONS OF TERMS AND NAMES WITH WHICH A GROUND ENGINEER, HOLDING A "D" LICENCE, SHOULD BE FAMILIAR

CLASSIFICATION HEADINGS

1. Air Navigation Directions
2. Materials
   - (*a*) Classification of Steels
   - (*b*) Ferrous Material
   - (*c*) Non-ferrous Material
3. Material Testing
4. Material Defects
5. Approved Protective Processes
6. Manufacturing Processes
7. Heat-treatment
8. Accessories
9. Engine Testing
10. Fuels
11. Engine Data

1. AIR NAVIGATION DIRECTIONS

Approved Firm. This is any firm approved by the appointed inspecting authority for the manufacture, inspection, and release of aircraft parts. (See page 3.)

Approved Release Note. A document covering the inspection and release of aircraft parts manufactured by an approved firm. The release note will include a certificate embodying the Air Ministry reference under which approval of the firm was granted.

Certificate of Airworthiness. This is a certificate given when a machine and its power plant comply with the prescribed regulations.

Ground Engineer. A person authorized to certify the safety for flight of an aircraft, or parts thereof, in accordance with the regulations in force.

"Type" Engine. An engine which has satisfactorily completed a Civil Type Test, and for which a technical certificate has been issued. "Subsequent" engines must be identical to the "Type" engine, except where approved modifications have been added.

2. MATERIALS

(*a*) Classification of Steels

Air-hardening Steels. These steels contain elements such as Ni and Cr, which have the effects of slowing down the transformation of the steels, when cooling through their critical points, to such an extent that rapid cooling becomes unnecessary.

Alloy Steel. An alloy steel consists of one or more elements other than carbon, added specifically to improve one or more of its useful properties. The elements V, Cr, Mn, Co, Ni, Mo, and W, all of which have high melting points, are those usually employed. For aircraft steels the common alloys are Ni from 3 per cent to 4·5 per cent; Cr from ·5 per cent to 1·5 per cent. The quantities and subsequent heat-treatments determine the ultimate strengths.

Austenitic Steel. This steel is usually high in Ni, Cr, or Mn. The physical properties cannot be varied to any great extent by the usual method of heat-treatment. It does not harden by a quenching treatment from high temperatures, and remains non-magnetic at ordinary temperatures. It is very resistant to corrosion and erosion by hot gases, and retains its strength well at high temperatures.

Carbon Steel. This embraces—

(i) Mild steel containing up to ·25 per cent C.
(ii) Medium steel containing from ·25 per cent to ·70 per cent C.
(iii) High carbon steel containing from ·70 per cent to 1·8 per cent C.

In all cases the C is combined as a carbide; in addition, Mn and Si may be present within prescribed limits.

Ternary Steel. This steel contains iron, carbon, and one alloying element only.

Quaternary Steel. This steel contains iron, carbon, and two alloying elements.

Complex Steel. This steel contains iron, carbon, and three or more alloying elements.

Stainless Steel. This is a steel with high Cr content. It is non-corrosive after heat-treatment has eliminated the free carbides. Stainless Cr-Ni steels are manufactured under the names of "Staybright," "Anka," etc. Steel to B.S. Specification S.62 is often used for inlet valves.

Straight Steel. This is a carbon steel which does not include any toughening elements such as Ni, Cr, etc.

(b) Ferrous Material

Case-hardening Steel. One containing not more than ·2 per cent of carbon. The following steels with proprietary names fall in this class—

"Ubas." This is manufactured by Messrs. Flathers, and the composition comes within B.S. Specification 2.S.14.

"Hicore." This is a nickel chrome molybdenum steel which conforms to B.S. Specification S.82.

Era H.R.1. This is a high nickel high chromium austenitic steel made by Messrs. Hadfields. The appropriate specification is D.T.D.49B. This material is used mainly for inlet and exhaust valves.

Hykro. This is a steel with high Cr content and is suitable for nitrogen hardening. Steel to B.S. Specification No. 306 is suitable for all engine parts. Steel to B.S. Specification No. 317 is used primarily for cylinders.

The Brinell hardness in both cases is about 850 after nitriding. See all "Nitralloy."

Invar. This is a nickel iron containing 36 per cent of nickel. It has an exceedingly low rate of expansion, and is very resistant to water corrosion.

K.E. 965. This is a high nickel high chromium austenitic steel made by Messrs. Kayser Ellison. The appropriate specification is D.T.D.49B. The steel is used principally for inlet and exhaust valves.

Nitralloy. A steel to specification D.T.D.87 that can be surface hardened by the Nitriding process. Specification D.T.D.228 is also suitable, but owing to the absence of Al the process takes longer. Steel to B.S. Specification No. 228 is more ductile than other nitriding steels and is less suitable for nitrogen hardening, the Brinell hardness being about 650. Steel to B.S. Specification No. 87 has a Brinell hardness of about 1050 after nitriding. See also "Hykro."

N.M.C. This is a 12 per cent nickel manganese chrome steel made by Messrs. Firth Derihon, which conforms to Specification D.T.D.247. It is used extensively for valve seatings, because of its resistance to shock loadings at high temperatures.

Pitho. This is a high carbon steel used for valve ends and similar parts.

Sandvik. This is a nickel chrome air-hardening steel.

Thermocrome. This steel conforms to D.T.D. Specification No. 233 and is used by Messrs. Wellworthy Ltd., for piston rings.

(c) Non-Ferrous Material

Alpax. This is an aluminium alloy suitable for intricate castings. It contains about 13 per cent silicon, which facilitates the flow of metal. It conforms to B.S. Specification L.33. In the fully modified condition, the ductility and physical properties of the material are improved. "Wilmil" is the name of a similar class of material.

Bearing Metal. The following are the most usual crankpin bearing metals—

Hoyt 11, which conforms to B.S. Specification 2.B.22.
Hoyt 11.D., which conforms to Specification D.T.D.214.
Hoyt 11.D. (modified). Specification D.T.D. 244.

The latter two materials are used to some extent on Bristol and Armstrong-Siddeley engines.

CADMIUM, which conforms to Specification D.T.D.217.
LEAD BRONZE, which conforms to Specifications D.T.D.229 and 274.
GLACIER, which conforms to B.S. Specification 2.B.21.

Birmabright. This conforms to D.T.D. Specification No. 165 and contains ·5 per cent Mn, 3·5 per cent Mg, the remainder being Al.

Brightray. This consists of 80 per cent Ni and 20 per cent Cr. It is used primarily for coating the head and seat of inlet and exhaust valves and provides a protection against corrosion at high temperatures and lead attack.

Carobronze. This is an extruded material containing 92 per cent pure electrolitic copper and 8 per cent tin; ·25 per cent of phosphorus is present, but this is controlled. The appropriate specification is T.52. The material is normally used for bushes, and is supplied in tubular form, either heat-treated, hard, or annealed.

Constantin. This consists of 45 per cent Ni and 55 per cent Cu. It is used primarily for thermo couples.

Cupro Nickel. This consists of 79·6 per cent Cu, 20 per cent Ni, 0·4 per cent Mn.

Duralumin. This is an aluminium alloy conforming to Specification 4.L.1. It can be obtained in all the usual forms, including extruded and forged material. It requires heat-treatment followed by a natural age-hardening.

Elektron. This is a name covering a range of magnesium aluminium alloys. It is available as castings, bars, tubes, forgings, and can also be extruded. Specification D.T.D.88B covers the requirements of forgings, and Specification D.T.D. 59A covers those for castings. Its specific gravity is 1·82.

Gallimore Metal. This consists of 90 per cent Cu and 10 per cent Sn and is used largely in radiator construction.

Hiduminium. This covers a range of Messrs. High Duty Alloys, aluminium alloys evolved by Messrs. Rolls-Royce. The analysis includes Cu, Ni, Mg, Fe, Si, and Ti. The latter is understood to act as a refining agent. The following specifications relate to this class of material—

L.40, R.R. Specification 56, for forged work.
D.T.D.131A, R.R. Specification 53, for die-cast pistons.
L.42, R.R. Specification 59, for forged pistons.
D.T.D.133B, R.R. Specification 50, for sand and die castings.

Inconel. This consists of 75–80 per cent Ni, 11–13 per cent Cr, 6–8 per cent Fe, and impurities up to 2 per cent. Its ultimate stress fully annealed is 35 tons per sq. in., but as hard-drawn wire it is as high as 85 tons per sq. in. It has a high resistance to corrosion at high temperatures and is used for exhaust manifolds. It can be brazed, silver and soft soldered, and welded. It is not subject to weld decay, but a protective flux is applied as a paste. The welding wire should be bright annealed and soft, either cut in strips from the sheet or in the form of wire.

Monel Metal. This material contains from 64 per cent to 70 per cent Ni, 2·5 per cent (max.) Fe, 2 per cent (max.) Mn, and the remainder copper. D.T.D. Specification 10B covers sheet, and D.T.D. Specifications 192, 196, and 200 cover bars, etc. This material is resistant to all forms of corrosion, and has been used extensively for valve seatings.

Stellite. This comprises 4 to 16 per cent W, 30 per cent Cr, and 66 to

54 per cent Co. The higher the tungsten, the more brittle the material becomes. It is highly resistant to hot and cold corrosion attack of leaded fuel, and has been used as a facing for valve seats and seatings. It is also applied to the tips of valve stems on account of its resistance to abrasion.

Stabalite. This is a material used for mouldings in ignition coils and similar electrical fittings.

Textolite. This is made up of layers of canvas impregnated with synthetic resin, which are compressed together in a hot press. It is used for gear wheels of magnetos.

" Y " Alloy. This is an aluminium alloy which is largely used for pistons. The material is resistant to atmospheric and marine corrosion. It has good physical properties at high temperatures. Specification L.43 covers forgings and stampings, and B.S. Specifications 2.L.24 and L.35 cover castings, etc.

3. MATERIAL TESTING

Brinell Number. (See page 13 for full particulars.) In addition, tables are included in Appendix I.

Brittleness. This is the opposite property to "toughness" and is the lack of resistance to fracture when subjected to shock or other loads.

Creep Stress. The permanence of dimensions on test bars under continuous stress at room and/or elevated temperatures. It is a fatigue stress set up by a dead load, when stretching may occur considerably below the normal yield point, particularly at elevated temperatures. The load, period of application, and temperature range are important factors.

Ductility. The property of being permanently extended by a tensile stress.

Elasticity. The capacity of a material to return to its original dimensions on releasing the load causing the change in dimensions.

Elongation. (See page 7 for full particulars.)

Etching. The application of an acid solution to finished steel parts, after immersion in petrol and caustic soda to remove grease, etc., in order to show up any cracks or surface defects. The deposit so formed is removed with acetone and the part is then dried, after which acid would ooze from any cracks that may be present.

Hardness. The degree of resistance to penetration or wear by abrasion.

Impact Value. (See page 12 for full particulars.)

Limit of Proportionality. This in effect is the elastic limit of a steel, and is the point of a stress-strain curve where it ceases to be proportional.

Malleability. The property of being permanently extended either by forging, rolling, etc.

Modulus of Elasticity — When a tensile load is applied to a part, the modulus of elasticity (E) may be stated as the ratio of the load applied, to the extension produced, within the elastic limit, i.e. $E = \frac{\text{stress}}{\text{strain}}$. It is fairly constant for any given range of materials. For example—

For steels $E = 30{,}000{,}000$

For aluminium $E = 10{,}000{,}000$

Proof Stress. (See page 12 for full particulars.)

Reduction of Area. (See page 12 for full particulars.)

Stress. This is the resistance to change or deformation produced by an external load. It can be either tension, compression, or shear.

Strain. This is the deformation produced by a stress.

Sulphur Prints. If sulphur is well distributed in a steel it is not detrimental; but if sulphides are concentrated in large patches serious weakness in the metal may result. The following is a check for the presence of sulphur. The surface of the steel to be tested must be perfectly smooth, and all tool marks eliminated by progressive grades of emery cloth. A piece of bromide printing paper is soaked in a 5 per cent solution of H_2SO4 in water for a few minutes, and then placed on the prepared steel surface. Bubbles and excess liquid are squeegeed off, and after five minutes the paper is removed, washed in water, and fixed in hypo in the ordinary way. Sulphur, if present in excess, comes in contact with the acid and H_2S gas, which is liberated, blackens the printing paper. This procedure is indefinite for stainless steels.

Tenacity. The property of resisting fracture when under a tensile stress.

Toughness. The resistance to fracture when subjected to bending, torsion or shock loading.

Ultimate Stress. (See page 12 for full particulars.)

Yield Point. (See page 7 for full particulars.)

4. MATERIAL DEFECTS

(Ferrous)

Clink. Internal cracks in steel produced by tensile stresses set up in the ingot, probably as a result of too rapid heating.

Corrosion. This is the destruction of metal or alloy by chemical means.

Decarburization. This is the loss of C from the surface of steel. Iron reacts with O, forming "rust" at ordinary temperatures and adherent oxide scale on hot rolled or forged material. When reheated, the C in the adjacent steel begins to react with the iron oxide, which is reduced, the product of the reaction escaping as a gas. Migration of C is rapid and decarburization may take place to a depth of several thousandths of an inch.

In oxy-acetylene welding, the surface of the base metal and the welding rod may both become coated with iron oxide or scale while heating up to welding temperature and must be removed to secure a sound weld.

Erosion. This is loss of metal either rubbed or washed away.

Fins and Flashes. These are formed during the process of rolling the blooms into bars. They may become "laps" during subsequent passes through the rollers.

Flake or Snowflake. When an ingot is worked, pockets may occur in the steel where hard segregated layers of cementite have not properly welded together owing to the evolution of dissolved hydrogen. The pocket, or cavity, has a bright silvery appearance, and is of circular form. The bright surface is due to the fact that no oxidization has occurred. The presence of an excess of Mo and the lack of control of the treatment of the ingot is thought to be associated with this defect; in addition, forging lessens the susceptibility to flake formation.

Hair-cracks. (See page 14 for full particulars.)

Laps. These are analagous to "roaks," except that they usually appear on the surface of the steel. Molten metal may splash on to the sides of the ingot mould when pouring, and then oxidize, being subsequently covered by rising fluid. They become much elongated by subsequent rolling. "Laps" and die-marks in bars, etc., may develop into cracks during subsequent heat-treatment.

Pipe. (See page 15 for full particulars.)

Roaks. These are cavities or blow-holes of carbon monoxide gas in the steel which become oxidized, and do not weld up again on subsequent working. When the steel is rolled into bars they appear as elongated cracks.

Seams. These are external flaws produced on the surface of tubes as a result of dirt on the die during the drawing operation.

Segregation. This refers to the segregation of C.S.P., etc., when cooling a mass of molten steel, and usually occurs near the top of the ingot, which is the last part to solidify. The carbon can, however, be partially redistributed by reheating.

Slag Inclusions. These often accumulate where "pipe" is found, and can be associated with insufficient skimming of the molten steel prior to pouring. They may also be present as oxides, sulphides and silicates, on the surface of the ingot, but would normally be removed when machining the outer skin prior to further working of the metal.

Weld Decay. This is a defect which may occur during the welding of stainless steel of the 8/18 Ni-Cr class, and is a carbide precipitation followed by inter-crystal corrosion resulting in the embrittlement of the material. Close control of the temperature is essential, and normalizing will not restore the structure. (See page 19.)

(NON FERROUS)

Blisters. These may appear on Al alloys during heat-treatment due to the release of free hydrogen which should have been removed by prior heating in a vacuum, a salt bath, or an electric oven, the latter being preferable. The presence of water vapour is undesirable.

Ribboning. The segregation of Pb in lead bronze bearings which after running have the appearance of irregular cracks, but which under a magnifying glass are found to be full of Pb.

5. APPROVED PROTECTIVE PROCESSES

(*Only a brief description of each process is given*)

Aluminizing. This consists of spraying the steel parts with molten Al, using a pistol for the purpose. It is then covered with bituminous paint prior to heating at 800° C. for about 20 minutes. When cold, the surface is smoothed with a scratch brush. The coating is ·007 in. minimum thickness and has a silvery appearance. Penetration is several thousandths of an inch deep. D.T.D. Specification No. 907 relates.

Calorizing. The steel part is packed in a drum containing granulated aluminium and heat applied externally. Alternatively, the part is immersed in a bath of molten aluminium. Steel so treated will withstand high temperatures without undue oxidization or deterioration. The process lends itself, therefore, to the protection of exhaust manifolds, stub pipes, etc. This process does not give just a coating of aluminium, but actual impregnation of the base metal.

Cosletizing. This process provides a protective coating on iron and steel parts against rusting and corrosion. The process is somewhat similar to parkerizing, referred to later, except that the composition of the bath includes zinc phosphate, and phosphoric acid.

Fescolizing. This is the electrical deposition of metal, but differs from electroplating as regards the interlocking between the base and the applied metals which is obtained by the fescolizing process. The deposition is done in a cold bath, and perfect adhesion and cohesion are claimed. Nickel, chromium, and cadmium are usually employed.

Inhibitors. These are compounds which may be added to various

supplies to prevent or restrain oxidization. The following are some of their applications—

(i) Addition to ethylene glycol tends to counteract radiator corrosion. Cupro nickel tubes, however, appear to be immune.

(ii) Tin compounds are used in lubricating oil with a view to retarding sludging.

(iii) During the pickling of wire, oxidized particles are rendered harmless by a suitable inhibitor.

(iv) Thin coatings are applied, by spraying, to bores of cylinders to protect them during storage.

Chromate Treatment. This is an external protection for magnesium alloy castings against corrosion. The part, after thorough cleaning, is immersed for several hours in a boiling solution containing potassium and ammonium di-chromate. When it is quite dry, it is usual to apply a coating of cellulose enamel, as the surface provided by the chromate treatment would not otherwise withstand the normal usage to which the part may be subjected.

Japanning. This is the application of enamel to a part in any manner, either for protective or decorative purposes.

Metallization. This is a protective process obtained by spraying molten metal on to the part to be protected. Aluminium and copper are usually employed for this purpose. In the case of exhaust manifolds and stub pipes, the process is completed by covering the coating with a bitumastic paint. and then subjecting the part to suitable heat-treatment in order to effectively bond the aluminium to the steel.

Parkerizing. This process provides a protective coating on iron and steel parts against rusting and corrosion. A preliminary cleaning of the surfaces should be carried out by sandblasting, after which the part is immersed for a period up to three hours in a boiling acid solution containing iron phosphate. The dimensions of the parts, as also in the case of cosletizing, are not materially altered.

Platinizing. This provides a protective coating of zinc to the external surface of air-cooled cylinders and other steel parts. The surfaces that are not required to be coated are suitably protected. The article is packed in a metal container with zinc dust, and subjected to a prolonged heating at a suitable temperature.

Sheradizing. This is a process for protecting the surfaces of easily corrodible steel parts with a coating of less corrodible metal, viz. zinc. The articles are heated at a relatively low temperature in contact with zinc dust; considerable alloying takes place although a thickness of only about ·0005 in. remains on the surface. The articles are often "Rumbled" in a barrel, to ensure uniform contact with the metallic powder.

D.T.D. Specification No. 908 relates.

6. MANUFACTURING PROCESSES

Brazing. See page 18 for particulars.

Case-hardening. (See page 30 for full particulars.)

Cyanide Hardening. This consists of the absorption of C into the surface of steel parts whilst immersed in a liquid salt bath composed of sodium cyanide and sodium carbonate. The temperature of the bath may be between 800° C. and 950° C. and if the parts are left in for a long period, refining of the core may be required, followed by a normal quench in water. The following points should be noted—

(i) Parts should be dry and free of grease when lowered into the bath in a sieve or perforated ladle.

(ii) Penetration up to ·010 in. can be obtained and the surface is free of scale.

(iii) Cellulose enamel is a protection against the salts, but Cu is not.

(iv) A hood is required to carry away irritating fumes from the bath.

Dynamic Balancing. (See page 27 for full particulars.)

Static Balancing. (See page 27 for full particulars.)

Etching. Parts are immersed in an etching bath to show up surface defects. When etching steel, occlusion of hydrogen may occur particularly with those of low ductility, when penetration is greater. Heat-treatment after etching is essential. This can be done by heating the part from 100° C. to 150° C. for one hour, either in an oven or an oil bath.

Honing. This process applies largely to cylinder bores, and consists of polishing the surface after the final machining operation. The hone incorporates a number of spring-loaded grinding stones, and is arranged to reciprocate at the same time as it rotates. The grade of stone, the nature of the lubricant, and the speed of operation are all important.

Nitriding. See page 32 for particulars.

Patenting. A heating process, introduced in the manufacture of steel wire, to encourage crystal growth, prior to drawing.

Pickling. This is done by immersing steel parts in an acid bath in order to clean the surfaces and remove scale or oxide films. With this process there is danger, due to penetration of the acid and resultant weakening of the crystal boundaries, particularly if the part is left a long time in the bath. Subsequent heat-treatment is of no avail, and an inhibitor should, therefore, be introduced into the solution.

Scintilla Hardening. This is a simple method of securing a skin-hardened surface on case-hardening steels, but is not extensively used on aircraft engine parts. The part is heated, sprinkled with scintilla powder, and quenched. The hardening penetrates to a depth of from ·002 to ·003 in.

Tricolizing. This consists of the electrical deposition of metal, principally iron, on steel parts. Its application to aero-engines is mainly in restoring housings and journals that have worn beyond the maximum permissible dimensions. The built-up part is then restored to its correct dimensions by grinding in the ordinary way.

Welding. See page 19 for full particulars.

7. HEAT-TREATMENT

(Ferrous)

Annealing. (See page 28 for full particulars.)

Burnt Steel. When a steel is heated to a high temperature, fusion may occur in the outer layers. Decarburization is pronounced, and oxide films may be found in the grain boundaries of the ferrite and pearlite, and cracks are likely to occur. The cracks and brittle structure can only be removed by re-melting the steel.

Cold Short. This is a condition of steel when hammering or rolling, below a dull red heat, will result in fracture or cracking.

Critical Point. (See page 27 for full particulars.)

Equilibrium Value. The variation in change point temperatures on cooling and heating a steel.

Hardening. (See page 30 for full particulars.)

Normalizing. (See page 29 for full particulars.)

Recalescence Point. The point on the cooling curve of a steel where the carbides are precipitated. This is accompanied by a slight rise of

temperature. In wire drawing, the red-hot wire may be seen to increase momentarily in brilliance as it cools through this point.

Refining. (See page 32 for full particulars.)

Solid Solution. This is the result of the absorption of one solid by another, just as water absorbs sugar. In its application to steel, C is absorbed by the ferrite.

Tempering. (See page 30 for full particulars.)

Temper Brittleness. This is sometimes known as Krupp Krankheit. Certain nickel chrome steels, when subjected to slow cooling from their temperating temperatures, show very low impact values on the notched bar test, and are consequently brittle. Small quantities of Mo normally ensure freedom from temper brittleness.

Micro-Structures

Austenite. A solid solution of C in Gamma iron formed at temperatures above the upper critical range and partly maintained below this range by rapid quenching from a high temperature.

Cementite. Carbide of iron, Fe_3C (6.7 per cent C and 93.3 per cent Fe). Cementite is "combined" in Gamma iron but crystallizes out in Alpha iron.

Dendrite. Steel which has a coarse "fir-tree" type of micro-structure. Considerable segregation of carbon occurs during the solidification of the steel in the ingot mould, and is only partly dispersed by subsequent treatment and working.

Ferrite. This is pure iron. It is soft and ductile and has practically no hardening power. Crystals are cubic in shape.

Pearlite. This is a mixture of Cementite and Ferrite and is formed when a steel is cooled normally through the upper critical range temperature.

Martensite. This is a hard, brittle mixture of Carbide of Iron with Alpha iron, and is obtained by rapid quenching of the steel from above the upper critical range temperature.

Sorbite. This is the last stage of transformation of Martensite into lamillar Pearlite. The stages being Martensite, Troostite, Sorbite, and finally Pearlite.

Troostite. This is the first breakdown product of Martensite. When a steel is reheated (tempered) at a low temperature, the carbide commences to separate in a finely divided state. It can also be formed if quenching is not rapid enough to preserve the Austenite but too rapid to form Pearlite.

Macro-etching. The structure of the material is made visible to the naked eye by treatment with suitable reagents, usually acids in the case of steel and solution of caustic soda in the case of non-ferrous materials, such as Al.

Micro-photograph. This is a photograph of the specially prepared surface of a piece of metal after magnification up to 250 times. The prepared surface is etched with various reagents according to the class of material.

(Non-Ferrous)

Age-hardening. This is hardening of certain aluminium alloys through the breakdown of the solid solution over a period of time at room temperatures. "Precipitation heat-treatment" is artificial age-hardening by subjecting the part to a temperature usually below 200° C.

Modified. A term implying that the Si in Si-Al alloys is minutely dispersed, and the alloy is uniform and free from hard inclusions. This result is obtained by suitably fluxing the molten Al when adding the 50/50 Si-Al compound.

8. ACCESSORIES

(CARBURETTOR)

Accelerator Pump. This pump injects fuel into the choke tube whenever the throttle is opened, the quantity of fuel being proportional to the amount of throttle movement. There is also a delayed action pump incorporated on some carburettors.

Automatic Boost Control. This mechanism automatically regulates the boost pressure, so that the specified boost cannot be exceeded.

Boost Gauge. An instrument incorporating an aneroid which records the pressure in the induction system above or below that of the atmosphere at sea-level. It should read zero at standard atmospheric pressure, namely, 760 mm. (engine stationary).

Balance Pipe. A pipe or passage incorporated in the carburettor to balance the air pressure between the float chamber and the air intake.

Choke Tube. A restricted and calibrated passage situated between the air intake and the throttle orifice.

Diffuser. A component of a carburettor, usually consisting of a round perforated tube, which assists in atomizing the fuel before it enters the choke tube.

Mixture Control. This is sometimes referred to as altitude control, and consists of a valve by means of which the mixture strength can be varied to accommodate conditions at altitude.

Power Jet. A jet supplementing the normal fuel supply from the main jets which comes into operation at throttle openings about or above 9/10ths power. The jets are normally adjustable cam-operated needle valves.

Reference Jet. This is a jet used for calibrating scale plates on apparatus used for checking standard jets. The reference jet gives the flow in cubic centimetres per minute of pure benzole under constant pressure head of 50 cm. at 60° F. Standard jets must be accurate to within plus/minus 1 per cent up to 200 c.c. flow per minute and plus/minus ½ per cent for 200 c.c. flow per minute and above.

(ELECTRICAL)

Bonding. This is a means of making a complete "Earth" throughout the engine, thus preventing a tendency to electrical leakage, in the form of a spark, between any insulated parts.

Condenser. This comprises a large number of strips of tin foil insulated from each other by sheets of mica and so arranged that all the alternate sheets of foil protrude from one end of the pack and are electrically joined together. The other strips protrude from the other end of the pack and are also joined together. A high potential can by this arrangement be built up. The condenser prevents arcing at the contact-breaker points.

Polar Inductor Magneto. This type of machine has a stationary armature in which the primary circuit is generated and the secondary current induced. The E.M.F. reaches a maximum four times during each revolution of the rotating member (the polar inductor), thus providing four sparks per revolution. It operates at half the speed at which a rotating armature type of magneto does on a similar engine.

Safety Spark Gap. This is required because any undue rise of voltage, resulting from a sparking plug lead becoming detached or any other breakdown in the secondary circuit, would otherwise result in the possibility of damage to the insulation of the armature. The safety gap provides a path for the spark discharge to earth when there is not the usual path across the electrodes of the sparking plugs.

With B.T.-H. magnetos, a brass point from the distributing brush box

directed towards the slow speed gear wheel, and a serrated stud screwed into the gear wheel, constitute the poles of the gap. In Watford magnetos, a point from the secondary collector segment to a fixed earth point on the body of the magneto provides the gap.

Screening. The magneto, high-tension leads and sparking plugs are earthed separately from the engine, to prevent wireless interference.

(Airscrews)

Adjustable Pitch. The pitch setting of the blades is effected with the engine at rest.

Variable Pitch. The pitch setting is varied in flight to either coarse or fine pitch.

Constant Speed. A unit controls the movement of the blade settings to maintain a constant engine speed.

Controllable Pitch. This is similar to the constant speed airscrew but in addition the unit incorporates mechanism to vary the spring load on the governor and permit engine revolutions to be maintained by the pilot at any selected speed.

Feathering. The blades automatically revert to full coarse position when the engine comes to rest.

9. ENGINE TESTING

Boost Pressure. See paragraph 5 of Leaflet C2 (A.P. 1208).

Detonation. Also commonly known as "knocking" or "pinking." It is the spontaneous combustion of some portion of the charge, in such a manner that an extremely sudden and high pressure wave is generated, which on striking the combustion chamber walls causes the "ringing" or "pinking" sound.

Gate Throttle Power. See paragraph 14 of Leaflet C2 (A.P. 1208).

International or Rated Power. See paragraph 6 of Leaflet C2 (A.P. 1208).

International R.P.M. See paragraph 5 of Leaflet C2 (A.P. 1208).

Maximum Permissible Boost Pressure. See paragraph 10 of Leaflet C2 (A.P. 1208).

Pre-ignition. This is the ignition of a charge before it is fired by the sparking plug, and is caused by some overheated part, such as the sparking plug, exhaust valve, or incandescent carbon.

Rated Altitude. See paragraph 8 of Leaflet C2 (A.P. 1208).

Rated Boost Pressure. See paragraph 11 of Leaflet C2 (A.P. 1208).

Sea-level Power. See paragraph 12 of Leaflet C2 (A.P. 1208).

Specific Fuel Consumption. This is fuel consumption in pints b.h.p./hr. under any specific set of conditions, such as weakest maintained, normal rich, etc.

Weakest Mixture for Maintained Power. This represents the weakening of the mixture control on the carburettor to give a drop in h.p. between 0 and ½ per cent, or the weakest mixture with which an engine will run without undue overheating.

10. FUELS

Anti-knock Fuel. A fuel to which benzole, T.E.L., etc., has been added in order to suppress detonation which might otherwise be expected with high compression engines using standard fuel.

Aromatics. These are natural anti-knock constituents of a fuel and include benzene, toluene, and xylene.

Benzole. This consists of benzene plus a trace of toluene. It has the effect of increasing the anti-knock value of a fuel. It has a freezing-point of plus 5° C.

B.Th.U. This stands for British thermal unit, and is the amount of heat required to raise 1 lb. of water at its maximum density, 1° F.

Calorific Value. This is the heat value of a fuel. Aviation petrol has from 18,000 to 18,700 B.Th.U's per lb. Aromatics have from 17,300 to 17,800 B.Th.U.s per lb.

Cracked Spirit. This is a product of the high temperature distillation of crude oil from which petrol is normally distilled. Fuels of good anti-knock quality are obtained by this process.

Ethyl Fluid. This consists of tetra-ethyl lead, 61 per cent by weight; ethylene di-bromide, 36 per cent by weight; pink colouring matter, ·2 per cent. Kerosene and impurities the remainder.

Octane Number. This is the anti-knock value of a fuel. The fuel is tested on the standard knock-testing engine, and the degree of detonation is measured in relation to a reference fuel, the detonation characteristics of which are known. The reference fuel consists of a mixture of iso-octane (low detonation spirit) and normal heptane (high detonation spirit). The octane number is the percentage by volume of the former in an iso-octane-heptane mixture, which matches the fuel to be tested. In view of the cost of this reference fuel, sub-standard fuels are used. Fuel to Specification D.T.D.134 had an octane number of 75 to 76. Fuel to Specification D.T.D.224 has a minimum octane number of 77. Fuel to Specification D.T.D.230 has a minimum octane number of 87, with up to 4 c.c. of T.E.L. (not fluid) present. It is tinted pink and 100 octane fuel is tinted green.

Petrol. This is a trade name for a spirit consisting of a mixture of volatile fractions of the paraffin, naphthene, and aromatic series of hydrocarbons.

Tetra-ethyl Lead (T.E.L.). This is an anti-detonant, which is added to a fuel as "Ethyl Fluid," up to 4 c.c. of T.E.L. per gallon of fuel.

11. ENGINE DATA

Torque or Turning Moment. This is known as a "couple," that is a force acting at a given distance from a centre so as to produce a turning or twisting moment.

Thus, if W lb. act at the end of an arm L ft. long.

$$T \text{ (or Torque)} = W \times L \text{ lb.-ft.}$$

Now Work equals the force × distance moved.

Therefore, the work done by T lb.-ft., when the arm (L) turns through an angle of θ radians

$$= W \times L \times \theta \text{ or } T\theta \text{ ft.-lb.}$$

If N = revolutions per minute the distance travelled by the force
= $2\pi N$ radians and work done during N revolutions
= $2\pi N T$

$$\text{From which B.H.P.} = \frac{2\pi N T}{33{,}000} = \frac{N T}{5{,}253}$$

$$\text{and } T = \frac{\text{B.H.P.}}{N} \times \frac{33{,}000}{2\pi} = \frac{\text{B.H.P.}}{N} \times \frac{5253}{1} \text{ lb.-ft.}$$

Note. A radian (θ) is the angle subtended at the centre by a circular arc of length equal to the radius.

$$\text{Thus } \theta = \frac{180^\circ}{\pi} = 57.295^\circ$$

$$\text{and } \pi\theta = 180^\circ.$$

Horse-power. This is the unit of power, and equals 33,000 ft.-lb. or 33,000 lb. raised 1 ft. in 1 min.

I.H.P. This is indicated horse-power. The horse-power actually developed in the cylinder as calculated from an indicator diagram.

B.H.P. This is brake horse-power, the horse-power actually available at the airscrew.

Mechanical Efficiency. $\dfrac{\text{B.H.P.}}{\text{I.H.P.}}$

It is about 89 per cent for petrol engines. The remaining 11 per cent representing frictional and pumping losses.

Compression Ratio (n). The compression ratio of an engine is obtained from the formula

$$n = \frac{r + R}{r} \text{ or } \frac{R}{r} + 1$$

where R = the volume swept by the piston in the cylinder
r = the combustion space when the piston is at T.D.C.

M.E.P. This is mean effective pressure, and is the average pressure (lb. sq. in.) on a piston during one cycle. This can be ascertained by taking an indicator diagram with a Farnborough indicator, or similar apparatus. The brake mean effective pressure can be calculated from observed brake readings. For a four-stroke engine, the brake M.E.P.

$$= \frac{\text{B.H.P.}}{\text{R.P.M.}} \times \frac{66{,}000}{N \times S \times D}$$

where N = number of cylinders,
S = stroke (ft.),
D = area of the piston (sq. in.).

Volumetric Efficiency. This is the ratio between the volume of mixture taken into the cylinder during the induction stroke and the cylinder capacity at atmospheric pressure with the piston at B.D.C. This may be 80 per cent with a normally aspirated engine, but is increased on raising the induction pressure by supercharging.

Thermal Efficiency. The relation between the heat value of the fuel charge, etc., and the heat converted into actual work. It may be stated thus—

$$\frac{\text{Useful work done}}{\text{Total heat supplied}}$$

This is about 25 per cent for a petrol engine and slightly higher for a compression ignition engine.

Left-hand Engine. This is an engine in which the airscrew shaft rotates in an anti-clockwise direction viewed with the engine between the observer and the airscrew. With a right-hand engine the airscrew shaft rotates clockwise. This definition is applicable to both tractor and pusher engines.

APPENDIX III

CONVERSION FACTORS

1. Pressures
2. Volumes and Capacities
3. Weights
4. Linear and Surface Dimensions
5. Miscellaneous

1. PRESSURES

1 atmosphere .	=	A column of H_2O. 33·90 ft. high
	=	A column of Hg. 760·0 mm. high
	=	A column of Hg. 29·92 in. high
	=	14.69 lb. per sq. in.
	=	1·033 Kg. per sq. cm.
	=	1013·2 millibars
1 lb. per sq. in. .	=	A column of Hg. 52 mm. high
	=	A column of Hg. 2 in. high (approx.)
	=	A column of H_2O 2·31 ft. high
	=	0·07 kg. per sq. cm.
$\frac{1}{8}$ lb. per sq. in. .	=	A column of Hg 0·255 of an inch high
1 in. head of Hg. .	=	0·0344 Kg. per sq. cm.
	=	A column of H_2O 1·135 ft. high
	=	0·49 lb. per sq. in.
1 mm. head of Hg. .	=	A column of Hg. 0·039 of an inch high
	=	0·019 lb. per sq. in.
12 in. head of H_2O .	=	0·433 lb. per sq. in.
	=	A column of Hg. 0·882 of an inch high
12 in. head of fuel .	=	S.G. × 0·433 lb. per sq. in.
	=	A column of Hg. S.G. × 0·882 in. high
10 in. head of fuel (S.G. 0·76)	=	·274 lb. per sq. in.
12 ft. head of fuel (S.G. 0·76)	=	3·95 lb. per sq. in.
27½ in. head of H_2O .	=	1 lb. per sq. in.
1 ton per sq. in. .	=	1·575 kg. per sq. mm.
1 lb. per sq. in. .	=	0·0703 kg. per sq. cm.
1 kg. per sq. mm. .	=	1422·4 lb. per sq. in.
1 kg. per sq. cm. .	=	14·224 lb. per sq. in.
Exhaust back pressure correction		Add 1½ per cent of the observed b.h.p. for each lb. per sq. in. of pressure recorded in the manifold
1 per cent back pressure . . .	=	A column of H_2O 18 in. high (approx.)
1 millibar . . .	=	1000 dynes per sq. cm.

2. VOLUMES AND CAPACITIES

1 cu. cm. . .	=	0·061 cu. in.
	=	0·0018 pt.
1 cu. in. . . .	=	16·387 cu. cm.
	=	0·029 pt.
	=	0·016 litre
	=	0·0036 gal.
1 cu. ft. H_2O . .	=	28·375 litres or kg.
	=	6¼ gals. (approx.)

1 pint	=	0·125 gal.
	=	0·568 litres
	=	568·25 cu. cm.
	=	34·66 cu. in.
1 litre	=	0·220 gal.
	=	1000 cu. cm.
	=	1·760 pt.
	=	61·0 cu. in.
1 millilitre	=	1 cu. cm.
1 gallon (Imperial)	=	4·546 litres or kg.
	=	10·0 lb. H_2O (fresh)
	=	1·205 U.S. gal.
	=	277·3 cu. in.
1 cu. ft. H_2O per sec.	=	373·8 gal. per min.

3. WEIGHTS

1 cu. ft. of H_2O	=	62·42 lb.
	=	1000 oz. (approx.)
1 gal. of H_2O at 62° F.	=	10 lb.
1 lb. of liquid	=	0·8 ÷ S.G. pt.
1 pt. of liquid	=	1·25 × S.G. lb.
1 litre H_2O	=	61·0 cu. in.
	=	2·2 lb.
	=	1 kg.
1 oz.	=	28·35 grammes
1 lb. (Av.)	=	0·4536 kg.
1 gramme	=	0·03527 oz.
	=	0·565 drams
	=	1 cu. cm. of H_2O
1 dram (Av.)	=	1·773 grammes
1 kg.	=	2·205 lb.
1 lb. H_2O	=	27·69 cu. in.
	=	0·4536 litres or kg.

4. LINEAR AND SURFACE DIMENSIONS

1 in.	=	25·40 mm.
$\frac{1}{1000}$ in.	=	0·0254 mm.
	=	0·001 in.
1 cm.	=	0·3937 in.
1 mm.	=	39·37 thousandths of an inch
	=	0·0394 in.
1 sq. in.	=	6·4514 sq. cm.
1 sq. cm.	=	0·155 sq. in.
$\frac{1}{64}$ in.	=	0·015625 in.
	=	0·397 mm.

$\frac{1}{32}$ in.	= 0·03125 in. = 0·794 mm.
$\frac{1}{16}$ in.	= 0·0625 in. = 1·587 mm.

5. MISCELLANEOUS

(a) Power

1 British horse power	= 33,000 ft. lb. min. = 746 watts (amperes × volts) = 1·0139 × French horse-power = 42·4 B.Th.U./min.
1 French h.p.	= 0·986 × British h.p. = 75 kilogrammetres/sec.
1 kilogrammetre[1]	= 7·233 ft. lb.
1 ft. lb.	= 0·1382 kilogrammetre
1 British thermal unit (B.Th.U.)	= 778 ft. lb.

(b) Speed

1 mile per hour	= 0·445 metres per sec. = 1·467 ft. per sec. = 88 ft. per min.
60 miles per hour	= 88 ft. per sec.
1 knot (nautical mile)	= 1·152 statute miles per hour
1 knot	= 1853 metres
1 mile	= 1·609 kilometres
1 kilometre	= 0·621 miles

(c) Temperatures

Degrees Fahrenheit	= (Degrees Centigrade × $\frac{9}{5}$) + 32
Degrees Centigrade	= (Degrees Fahrenheit − 32) × $\frac{5}{9}$
Freezing point H_2O	= 0° C. = 32° F.
Boiling point H_2O	= 100° C. at 14·69 lb. sq. in. = 212° F. at 14·69 lb. sq. in. = 92·5° C. at 10,000 ft.
Absolute zero	= − 273° C = − 459·4° F.

(d) General

1 millivolt	= $\frac{1}{1000}$ volt
a milliampere	= $\frac{1}{1000}$ ampere
1 Radian	= 57·3 degrees.

[1] Work done by 1 kg. exerted through a distance of 1 metre.

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ELECTRICAL AND WIRELESS EQUIPMENT OF AIRCRAFT

INCLUDING THE REPAIR, OVERHAUL AND TESTING OF MAGNETOS

("X" LICENCE)

BY

S. G. WYBROW

A.M.I.E.E., A.M.I.M.E.

The Air Ministry, whilst accepting no responsibility for the contents of this book, recognizes it as a textbook that should prove to be of value to intending applicants for Ground Engineers' licences

Part V

CONTENTS

CHAPTER IV

CHAPTER V

CHAPTER VI

CHAPTER VII

INTRODUCTION

In the Air Navigation Directions, Section 11*c*, it is laid down that "The constructor shall ensure by suitable inspection that all engines, instruments, and parts (including wiring for electrical equipment other than wireless apparatus) that are fitted into the aircraft are so installed as to function correctly, and, if wireless telegraphy or wireless telephony apparatus is fitted, that the installation of such apparatus, including bonding and screening, is not such as to prejudice the operation of the aircraft . . . the individuals responsible for such inspection shall be indicated by signatures on the inspection record. . . ."

A motorless glider is probably the only form of heavier-than-air craft which has no electrical installation of any kind. The smaller types of light aeroplane may incorporate no electrical system beyond the ordinary engine ignition system, or they may be also equipped with electrical night flying equipment, which includes navigation lights, instrument lights, and electric landing lights or electrically ignited flares. The medium and larger types of civil passenger carrying aeroplanes will have, in addition, a wireless transmitting and receiving installation, and, possibly, wireless direction-finding equipment. They may also have such auxiliary services as cabin lighting, cockpit lighting, cooling fans, etc. On military types of aircraft we meet, in addition to the foregoing, such essentially military electrical equipment as bomb release gear, bomb fusing gear, torpedo release gear, identification lights, electrically heated clothing and guns, signalling lamps, cameras, etc. In both civil and military types of aircraft we may meet inter-connected electrical and wireless systems, i.e. where both systems draw energy from one common source.

Apart from the various electrical services referred to above, we may meet individual instruments which are electrically operated apart from any general electrical system installed on the aircraft. We have examples of these in the electrically operated engine revolution counters, electrically operated contents gauges, etc.

In discussing the electrical and wireless installations in use on aircraft, all calculations and problems in design will be carefully avoided. The primary object is to indicate to ground engineers, in broad outline, the basic principles of design, together with notes on the care and maintenance of equipment, fault localization, and repair. For these reasons a reference to the various electrical definitions and units which we shall be compelled to use is essential. There are a number of official publications dealing with various individual aspects of our subject, and in compiling this section free use has been made of the information contained in these, the principal of which are—

Air Publication 1208: *Airworthiness Handbook of Civil Aircraft.*
Inspection Instructions of the Aeronautical Inspection Directorate, Air Ministry.
Admiralty Handbook on Wireless Telegraphy.

Acknowledgment has also to be made of the courtesy and assistance received from The British Thomson-Houston Company Ltd.; Marconi Ltd.; Rotax Ltd.; Smith's Aircraft Instruments; Batteries Ltd.; The Plessey Co.; Record Electrical Co. Ltd.; Vickers Ltd., and the Edison Storage Battery Co. Ltd., in supplying information regarding their products.

One general observation remains to be made before proceeding to deal with the subject in further detail. Ground Engineers must realize that, apart from routine tests of the continuity of wiring and insulation resistance of an installation in an aircraft, their duties also include a visual examination of all the various components, instruments, and wiring comprising the various circuits, for correctness to specification requirements, drawing requirements, and standard of workmanship. In Air Publication 1208, *Airworthiness Handbook of Civil Aircraft*, is published a list of officially approved items of equipment, but the appearance of the name of any specific item of equipment in such a list does not absolve a ground engineer from the necessity for obtaining adequate documentary evidence, by way of an approved release note or equivalent means, of the correct manufacture, inspection and test of the item in question in accordance with the specification and/or drawings quoted in Air Publication 1208.

ELECTRICAL AND WIRELESS EQUIPMENT OF AIRCRAFT

CHAPTER I.

ELECTRICITY AND ELECTRIC CURRENTS

The Aether

THE aether is a universally diffused medium, which inter-penetrates all matter and extends immeasurably beyond the confines of the earth's atmosphere. It therefore occupies space, but research has not so far been able to show that it possesses weight, and for this reason it cannot be regarded as "matter." Our reasons for so confidently assuming the existence of this entirely intangible medium may be briefly summarized.

Enormous quantities of energy are radiated from the sun to the earth in the form of light and heat, and this energy travels through space which is known to be devoid of air or ordinary matter. Similarly, light and heat are radiated from incandescent lamps, although the bulbs of those lamps may have been exhausted of air and any other gas or matter. The question is, how does this energy travel across an apparently empty space? It is only reasonable to suppose that it has been "conveyed" across that space in a manner somewhat similar to the manner in which sound is conveyed from, say, an electric bell, across an intervening air space, to our ear. If we place an electric bell in a glass jar we shall find that as we exhaust the air from the jar we shall cease to hear the bell ringing, although we can see through the glass that the bell is still in operation. The reason for our ceasing to hear the bell when the air is exhausted from the jar is that we have removed the medium through which the sound waves are conveyed, viz. the air. The sun's energy must be conveyed to us either as an actual molecular movement, like the movement of individual molecules of water from the source of a river to its mouth, or as a wave motion, like the passage of sound through air. All experience and measurements go to show that light and electro-magnetic energy generally are conveyed or transmitted through space with a definite velocity, and we are led to the conclusion that all space is occupied by a medium which conveys the energy, and that this medium has properties different from those of ordinary matter. This medium is called the **aether.**

Movements of the aether are produced by the electric fields associated with electrons, and the **speed of propagation** of electro-magnetic disturbances of the aether is 186,000 miles per second.

All movements of the aether consist of electric and magnetic forces alternating in direction, and they produce a disturbance spreading outwards, which is called an electro-magnetic wave, or simply an **aether wave.** These waves produce different effects which require different methods of reception according to their frequency. The term "frequency" must not

be confused with the "speed of propagation." The **frequency** of a wave form simply refers to the number of complete waves or cycles per unit of length (or time, since the length and time are inter-dependent) and is a widely varying factor, whereas the speed of propagation is a fixed quantity, already referred to, of 186,000 miles per second.

Perhaps the difference may be most clearly comprehended by a hypothetical illustration. Suppose it were possible for two men to stand 186,000 miles apart, and each man to be holding one end of a long rope stretched between them. If one man agitates his end of the rope in an up and down direction he will produce ripples or waves in the rope which will travel along the rope to the other end. The first man can vary the size of the waves according to the manner and speed with which he agitates the rope, i.e. he can produce waves which measure, say, 3 ft. from crest to crest, or which measure, say, 6 ft. from crest to crest. These dimensions are analogous to the wave-length of an aether wave, and the number of complete waves which can be produced in a given time is the frequency, but the speed with which the waves travel along the rope from one end to the other is the speed of propagation. If, in this illustration, a wave travelled along the rope from one man to the other in 1 sec., it would travel at the same speed as the waves in the aether. Perhaps it will not be out of place to conclude this description of the aether with a summary of the most important kinds of aether waves known. (See table on opposite page.)

The method of converting wave-length to frequency is to divide 186,000 miles by the length of one wave, which will give the number of waves in that length, i.e. the number of waves propagated per second. For converting frequency into wave-length, the rule is to divide 186,000 miles by the frequency.

In other words

$$\text{Frequency} \times \text{wave length (miles)} = 186{,}000.$$

It should be remembered that frequency is often referred to in terms of kilocycles,

$$\text{i.e. } 1 \text{ kilocycle} = 10^3 \text{ cycles.}$$

So that 10^4 cycles is the same as 10 kilocycles.

The term "frequency" is the commonly adopted abbreviation of "frequency per second."

Electricity

The modern theory of electricity is termed the Electronic Theory. It must not be assumed that we have, as yet, any complete theory of the structure of the atom which absolutely and completely sums up all known facts concerning electricity, but the electronic theory of electricity is at present the universally accepted theory, and it is of the greatest possible help in explaining most electrical phenomena and especially in explaining the action of wireless valves. We shall have more to say on the subject under the heading of atoms and electrons.

Matter

Matter is anything which has weight and occupies space. Some kinds of matter are invisible, for example, air, hydrogen, etc. Matter is composed of innumerable separate particles, all of which, however, are spaced apart from each other. The smallest particle of matter which can exist as a separate entity is called a **molecule,** but this is a relatively large and very complex structure. The molecule of one substance is entirely different, both as regards composition and construction, from the molecule of

Wave-length (millimetres)	Frequency (per second)	Type of Wave	Type of Receiver
·000 000 01	3×10^{19} cycles	Gamma waves	Photographic plate
·000 063 80	$4{\cdot}7 \times 10^{15}$,,	X rays	or
·000 1 to ·000 2	3×10^{15} to $1{\cdot}5 \times 10^{15}$,,	Ultra-violet rays	Fluorescent screen.
·000 4	$7{\cdot}5 \times 10^{14}$,,	Violet light	The eye.
·000 45	$6{\cdot}7 \times 10^{14}$,,	Blue ,,	
·000 5	6×10^{14} ,,	Green ,,	
·000 6	5×10^{14} ,,	Yellow ,,	
·000 65	$4{\cdot}6 \times 10^{14}$,,	Orange ,,	
·000 8	$3{\cdot}8 \times 10^{14}$,,	Red ,,	
·0016 to ·1024	2×10^{14} to 3×10^{12} ,,	Dark heat or infra-red rays	The skin.
·2048 to 3·2768	15×10^{11} to $0{\cdot}9 \times 10^{11}$,,	Unknown	Unknown.
6·5536 mm. to 13,312 mm.	$4{\cdot}6 \times 10^{10}$ to $2{\cdot}2 \times 10^{7}$,,	Hertz radiation	An aerial and suitable detector circuits.
and up to 30 000 metres	and up to 10^{4} ,,	W/T waves	

any other substance. Molecules vary considerably in size and weight, but the largest is far too small to be seen under even the most powerful microscope.

Molecules are structures which are built up from much smaller particles called **atoms.** Both the chemical and physical properties of molecules are entirely different from the chemical and physical properties of any of the atoms which go to make up those molecules, except in the case of certain substances, which are called **elements.** In the case of an element, the molecules are structures consisting of from one to five atoms of exactly similar chemical and physical properties.

Apart from elements, we have other substances called **compounds,** and in these cases the molecules are structures consisting of two or more atoms having entirely different chemical and physical properties from each other and from the molecule which they produce. Thus the molecule of the element sodium consists of a single atom of sodium, the molecule of the element oxygen consists of two similar atoms of the element oxygen, and the molecule of the element nitrogen consists of three atoms of that element, whilst the molecule of the compound water consists of two atoms of the gas hydrogen combined with one atom of the gas oxygen, and the molecule of the compound known as mica consists of 42 atoms of five different kinds (i.e. potassium, oxygen, aluminium, silicon, and hydrogen). Air is neither an element nor a compound, but is a mechanical mixture (in varying proportions) of molecules of the gaseous elements oxygen, nitrogen, argon, and certain other rare gases.

It is believed that there are only ninety-two different kinds of atoms (i.e. elements) and that all other substances are compounds, consisting of molecules constructed from varying numbers and selection of atoms of these elements. Nearly all the ninety-two elements have been identified and isolated, but four or five still remain to be discovered, although our knowledge of this subject is so exact that practically all the chemical and physical properties of the unknown elements have already been forecast with considerable confidence.

Until recent years it was believed that the atom was the final subdivision of matter, but modern physical research has now demonstrated that atoms themselves are complicated structures which probably consist of a positively charged central nucleus together with an associated number of free **electrons** or charges of negative electricity. The electrons are mainly in violent motion in elliptical orbits round the central nucleus, and these orbits are of varying and relatively large dimensions. The central nuclei are presumed to vary in size and structure in the atoms of the different elements, the nucleus of the hydrogen atom being the smallest and simplest and being identical with the positive particle or **proton.** The following figure shows the assumed structure of three typical atoms, those of hydrogen, carbon, and oxygen.

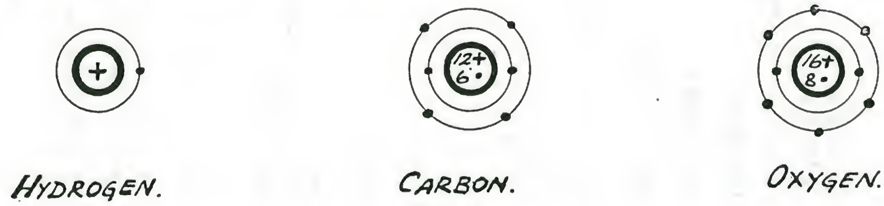


FIG. 1

It will be noted that the hydrogen atom consists of a central nucleus of one proton, together with one free associated electron; that of carbon

of a central nucleus of twelve protons and six "prisoner" electrons together with two free electrons in a small diameter orbit and four free electrons in a larger diameter orbit; that of oxygen of a central nucleus of 16 protons and 8 "prisoner" electrons, together with two free electrons in a small diameter orbit and six free electrons in a larger diameter orbit. There are strong reasons for presuming that there is a maximum of four elliptical orbits which may contain free electrons, but only the heaviest atoms will have free electrons in the outer rings. The smallest orbit is full when it has two electrons, the next when it has eight electrons, the next when it has eighteen, and the largest when it has thirty-two, but it is not necessary for any orbit to be fully occupied. The principal difference between the atom of one element and the atom of any other element is the varying number of free electrons associated with the central nucleus. In the formation of a simple compound there is a gain or loss of electrons by the constituent atoms, the outer electrons of the ions tending to assume an inert gas configuration. In common salt (Na Cl), for example, the sodium (Na) loses an electron, the chlorine (Cl) gains one.

The mass of the proton in an atom of hydrogen is 1,800 times greater than the mass of an electron, and thus it will be seen that practically the whole mass of an atom is located in the central proton. In the case of the hydrogen atom there is one electron associated with the proton.

Whilst the proton is regarded as being a body charged with positive electricity, the electron is a particle of negative electricity free from association with anything in the nature of matter as we know it. It not merely has a charge, but it *is* a charge, and apart from its charge it has no existence. There are 6×10^{18} electrons in a coulomb, and the diameter of an electron is $3{\cdot}74 \times 10^{-13}$ cm. These figures are so difficult to grasp mentally that it may be mentioned that if a single drop of water were magnified up to the size of the earth its atoms would be about the size of footballs, and the comparative size of the electron to the atom is about the same as a glass bead to an Atlantic liner.

Electrons can neither be created nor destroyed, but they can be made to move from one location to another, and thus to produce electrical phenomena. From this it will be seen that electricity cannot be produced or generated. A dynamo or battery is merely a device for setting electrons in motion from one locality to another.

As already stated, an atom of an element consists of a central nucleus with a certain number of associated free electrons, and the variation in the number of associated free electrons is the principal factor in determining the chemical properties of the element.

Whilst all electrons are precisely similar to each other, all nuclei are not similar to each other, but vary in size and magnitude of positive electrical charge. Thus, the value of the positive charge of the nucleus is normally neutralized by the aggregate value of negative charges of its associated free electrons, and the atom normally exhibits no electrical properties. But if an atom has an electron too many, or an electron too few, it does exhibit electrical properties, which can be detected by the electrostatic attractive and repulsive effects thereby produced, and the atom is said to be **ionized**. Thus, when an electron is added to, or taken from, a previously neutral atom or molecule, the charged particle which is thus formed is called an **ion**. If an electron is added to a normal atom there is a surplus of negative charge, and the resulting atom is known as a negative ion. The superfluous electron may move from a negative ion to a positive ion (i.e. an atom deficient of one electron) to produce two neutral atoms. It should be noted that the movement of

such electrons is away from the negative ion and towards the positive ion, i.e. the movement of electron currents is in the opposite direction from the popular assumption that credits "electricity" with moving from the "positive pole" to the "negative pole," an assumption dating from the time when the structure of the atom was not understood. Since this assumption, however, is still so universal outside the laboratory, and since its use is not likely to involve us in any difficulties, it will be adhered to in this volume, except where it becomes essential to draw special attention to the actual direction of flow of an electron current.

The movement of electrons between two points is normally referred to as an electric current, but a flow of electrons is more easily produced in some substances than in others. If it is a comparatively easy matter to produce a flow of electrons in a substance, that substance is regarded as being a good **conductor,** whereas a substance whose electrons offer considerable resistance to movement is regarded as being a bad conductor. Thus there is no definite line of demarcation between good conductors and bad conductors, since a flow of electrons can be produced in even a bad conductor if the electric field is sufficiently strong. The only really good conductors of electricity are the various metals, and the atoms of these substances will readily part with an electron under the slightest provocation. Even when there is a total absence of any electric force these electrons will be moving about quite freely, a regular interchange of electrons to and from the various atoms constantly taking place. But, because these electrons are moving aimlessly in all directions, there will be no resulting current. It is only when an electric force is applied to coerce all these electrons to move in one common direction that we have a current of electrons, or, more familiarly, a current of electricity. The individual electrons will not travel the whole way round a circuit. They will only travel to nearby atoms with which they will unite, but other electrons will instantly be liberated from those atoms

Good Conductors	Partial Conductors	Bad Conductors
Silver (annealed)	Cotton	Oils
Copper (annealed)	Wood	Porcelain
Copper (hard drawn)	Stone	Wool
Silver (hard drawn)	Marble	Silk
Gold	Paper	Sealing-wax
Aluminium	Ivory	Sulphur
Zinc		Resin
Platinum		Gutta-percha
Iron		India-rubber
Nickel		Shellac
Tin		Vulcanite
Lead		Mica
German Silver		Paraffin wax
Platinoid		Glass
Manganin		Dry air
Mercury		
Charcoal		
Graphite		
Acids		
Metallic salts		
Well-water (impure)		
The body		

to start their travels in the same direction as the first ones. Unless the current is flowing in a very good conductor, this interchange of electrons will not be taking place in all the atoms, but only in some of them. In fact, the proportion of free electrons to the total number of atoms is a measure of the conductivity of the medium, as well as of the magnitude of the current which is flowing.

The table on page 6 gives a list of some ordinary substances arranged in descending order of conductivity.

Before proceeding to deal with electrical units it is well to point out that there are two principal types of electric currents, viz. conduction currents and convection currents. **Conduction currents** are those currents which flow in a closed circuit consisting of a source of electric force (i.e. E.M.F., or electromotive force) and a continuous conductor. **Convection currents** are those which arise from the ionization of some medium in the circuit, e.g. between filament and anode of a transmitting valve, etc.

CHAPTER II

ELECTRICAL UNITS

HAVING now dealt in a general way with the nature of electricity and electric currents, we may proceed to define the various units which are used to measure electricity, electric currents, and the electrical properties of the various apparatus we shall be concerned with later on. It will be well to point out at the beginning that the various practical electrical units are based on what are known as C.G.S. units. The latter are the units used by scientists and will not directly concern us here. The initials stand for centimetre-gramme-second. The commonest practical units are the volt, ampere, and ohm, and we will deal with these first, afterwards proceeding to the less common ones, like the henry, farad, etc.

The force which moves, or tends to move, electrons in a definite direction is termed an **electromotive force,** or E.M.F., and its unit is the **volt.** For an electron stream to move at all it must move from a region of comparatively high pressure to a region of comparatively low pressure, i.e. there must be a difference of pressure, or **difference of potential,** between the two ends, and the greater this difference of potential the greater is the E.M.F. or voltage tending to move the electron stream. To produce a voltage, or E.M.F., therefore, we must create a difference of potential. In hydraulics, a difference of water level corresponds to our difference of potential, and the water pressure in a connecting pipe is the equivalent of our E.M.F. or voltage. As a greater pressure is necessary to force a given amount of water through a small pipe in a given time than is necessary to force the same amount of water through a larger pipe in the same time, so a greater E.M.F. or voltage is necessary to force a given amount of electricity through a small wire in a given time than is necessary to force the same amount of electricity through a larger wire in the same time. So we see that "potential" is analogous to "level," "difference of potential" to "difference of level," and "E.M.F." or "volts" to "pressure" or "lbs. per sq. inch." The volt, which is the practical unit of electrical pressure, is the E.M.F. or pressure necessary to force a current of 1 ampere through a resistance of 1 ohm. There are three different ways in which an E.M.F. may be produced, viz. (*a*) by immersing two dissimilar metals, or other substances, in certain liquids, e.g. acids of primary and secondary cells; (*b*) by heating the junction of two dissimilar metals, i.e. thermo couples; and (*c*) by cutting a conductor in a certain manner by magnetic lines of force, e.g. dynamo, alternator, transformer.

Having produced a current of electricity, its rate of flow is measured in **amperes.** It is to be specially noted that this unit is a measurement of "rate of flow" and not a measurement of "quantity passed." In hydraulics it is analogous to "gallons per minute," and not simply to "gallons." An ampere is a rate of flow of one coulomb per second, a **coulomb,** which is analogous to "gallon," being 6×10^{18} electrons. From this it will be noted that a current of electricity of 1 ampere is equivalent to a flow of 6×10^{18} electrons per second.

The next most important unit is the unit of resistance, which is called the **ohm.** It is analogous to the friction which is encountered by all moving bodies, and it represents the property of all matter of opposing the free passage of electrons through it. Just as the friction between two bodies

in relative motion will result in the conversion of a certain proportion of the energy of motion into heat, so the resistance of a body to the passage of a current of electricity will result in the conversion of a certain proportion of the energy of the moving electrons into heat. The less the willingness with which molecules receive and release electrons, the greater is the shock given to the atom, and consequently to the molecule, the greater the heat generated. The standard definition of the ohm is "the resistance of a column of mercury 106·3 cm. long, 1 sq. mm. in cross-section, and of a mass of 14·4521 grm. at a temperature of 0° C." A megohm is a million ohms, and a microhm is a millionth part of an ohm. When measuring "insulation resistance," say with a Bridge Megger, it is the passage of a very minute current through the substance that operates the instrument.

The "specific resistance" of a conductor is the resistance between opposite faces of a cm. cube, of that substance. Tables of the specific resistance of various conducting substances are made out usually at 0° C. since resistance alters with a change of temperature. Some examples of specific resistances per cm. cube are approx.—

Insulating rubber	=	$1{,}400 \times 10^{18}$	microhms
Distilled water	=	7×10^{18}	,,
Mica	=	4×10^{18}	,,
Mercury	=	94	,,
Platinum	=	11	,,
Copper	=	1·6	,,

Having now considered the three primary units concerned when a current of electricity is caused to flow in a circuit, we come to the fundamental law which connects those units. This is known as **Ohm's law** and states that the "current is directly proportional to the voltage, and inversely proportional to the resistance" or, more graphically,

$$\text{Current} = \frac{\text{Voltage}}{\text{Resistance}} \quad \text{or } C = \frac{E}{R}$$

This equation may, of course, by simple arithmetical transposition, be expressed as

$$\text{Voltage} = \text{Current} \times \text{Resistance}$$

or as

$$\text{Resistance} = \frac{\text{Voltage}}{\text{Current}}$$

It is very important to note, however, that this law only holds good when we are dealing with steady unidirectional currents. When we come to deal with alternating, or oscillatory currents, there are other factors to be considered which will modify the relationship expressed in these equations.

The practical application of Ohm's law to the solution of the problems met during the layout of an installation may be briefly discussed. By far the commonest problem is that dealing with determination of the size of cable required for a particular purpose. To take the simplest form of circuit, i.e. that consisting of a source of potential, such as a battery, in association with a "load," say a lamp, and the necessary connecting wires, we have—

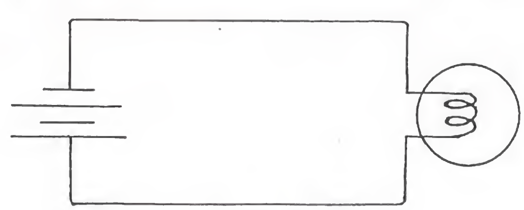


FIG. 2

In this case the resistance of the circuit is the sum of the individual resistances of the lamp, the wires, and the internal resistance of the battery. These factors being known, together with the voltage of the battery, it is a perfectly simple calculation from the formula $C = \frac{E}{R}$ to determine the value of the current which will flow, and hence the suitability of the wires in use. If, now, we consider the same circuit modified to supply two lamps, we are immediately faced with two alternatives, viz. (*a*) with the lamps wired **in series,** and (*b*) with the lamps wired **in parallel.** In the case of (*a*) the circuit becomes

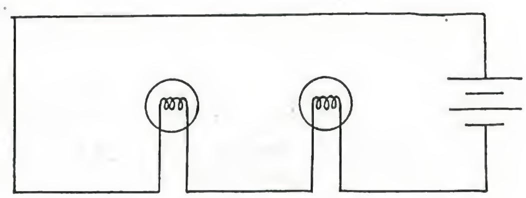


FIG. 3

and the problem is precisely the same as before, i.e. the resistance of the circuit is the sum of the individual resistances of the lamps, the wires, and the internal resistance of the battery. In the case of (*b*), however, the circuit becomes

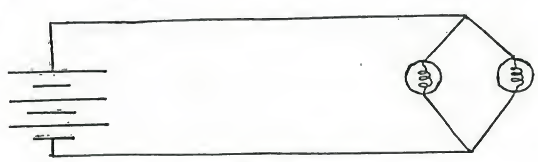


FIG. 4

and the total resistance is reduced. Where we have a number of resistances in parallel the rule for obtaining the resultant resistance is given by the formula

$$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} \text{ etc.}$$

Returning to our diagram, our method of procedure will be to find the resultant resistance of the lamps by means of the above formula, and to this result add the resistance of the wires and the internal resistance of the battery. Perhaps the reason for this procedure will be clearer if we regard the lamps as a compound resistance which is in series with the resistances of the wires and battery.

Where resistances are joined in series there will be a voltage drop at each resistance, and the current flowing is cut down accordingly. The total voltage drop is given by the formula

$$\text{Volts} = CR_1 + CR_2 + CR_3, \text{ etc.}$$

Before leaving the three primary units we should mention one other unit, the **Watt,** which is a derivative of two of them. When we have a current of electricity flowing in a circuit that current has two fundamental characteristics, viz. its voltage and its rate of flow, or amperage. It should be noted that the rate at which that current is capable of doing work will vary in direct proportion to both the voltage and the amperage. The

unit of power, or the rate of doing work, or the rate of producing energy, is the watt, and we therefore have

$$\text{Watts} = \text{Volts} \times \text{Amperes}$$

and the relationship of the watt to certain other fundamental units is—

$$\begin{aligned} 746 \text{ watts} &= 1 \text{ horse-power} \\ &= 550 \text{ ft.-lb. per second} \\ &= 33{,}000 \text{ ft.-lb. per minute} \\ 1 \text{ watt} &= 1 \text{ Joule per sec.} \\ &= \cdot 7373 \text{ ft.-lb.} \\ &= 10^7 \text{ ergs} \end{aligned}$$

Returning for a moment to the formula

$$\text{Watts} = \text{Volts} \times \text{Amperes} \quad . \quad . \quad . \quad . \quad (1)$$

and remembering from Ohm's law that

$$\text{Voltage} = \text{Current} \times \text{Resistance}$$

$$\text{and Current} = \frac{\text{Voltage}}{\text{Resistance}}$$

we can obtain, by simple substitution in (1)

$$\begin{aligned} \text{Watts} &= (\text{Current} \times \text{Resistance}) \times \text{Current} \\ &= C^2 R \quad . \quad . \quad . \quad . \quad . \quad . \quad (2) \end{aligned}$$

$$\begin{aligned} \text{and Watts} &= \text{Volts} \times \frac{\text{Voltage}}{\text{Resistance}} \\ &= \frac{V^2}{R} \quad . \quad . \quad . \quad . \quad . \quad . \quad (3) \end{aligned}$$

We thus have three equations for calculating electrical power in watts, from a knowledge of any two of the three units—volts, amperes, and resistance. A larger and more commonly used unit of power is the kilowatt = 1,000 watts. The Board of Trade unit is the kilowatt-hour, which is the energy expended by 1,000 watts acting for one hour.

CHAPTER III

MAGNETISM

WE have already referred to the mutual attraction between protons and electrons, which, under favourable circumstances, will unite to produce a neutral atom. It is a universal law of nature that similarly charged particles will repel each other. The phenomenon is explained by saying that the particles have associated with them an electric field, or state of strain in the aether, which is strongest nearest to the particle containing the charge and diminishing with distance. Thus, when a current of electrons is flowing along a conductor, the electric fields due to each electron set up a sort of swirl in the aether, much in the same way that a body moving on the surface of water will produce a swirl in the water. The swirl produced in the aether by the movement of electrons and their associated electric fields is termed a **magnetic field.**

Thus every conductor carrying a current of electrons is surrounded by a magnetic field, which takes the form of a band of concentric circles round the conductor, and both inside and outside it. The direction of rotation of the magnetic swirl depends on the direction of flow of the electron current. If we could hold a wire end on to our line of sight, and an electron stream in the wire was flowing towards our eye, then the positive direction of rotation of the magnetic swirl round the wire would be in a counter-clockwise direction, or, stated in another way, if a straight wire is held in the right hand with the thumb pointing along the wire in the direction of flow of the current then the bent fingers holding the wire indicate the direction of swirl round the wire of the magnetic flux. The whole of the magnetic field is filled with lines of force, i.e. the whole of the surrounding aether is in a state of strain, and there is a magnetic force at any point in the field. In the absence of any outside influence, the circles of magnetic lines of force are true circles concentric with the wire, but these circles may be distorted and drawn to one side by the influence of neighbouring magnetic fields.

When we come to consider the application of this phenomenon to a **solenoid** of wire, we find that the total resultant magnetic field has assumed the shape shown in Fig. 5.

That is, we shall have a strong and concentrated magnetic field within the solenoid, and a relatively weak, attenuated field, outside it. Such a magnetic field will behave in a manner similar to a magnetized bar of steel. We shall have a north pole at the end of the coil from which the lines of force emerge, and a south pole at the end where they enter.

Here, again, we have a simple rule for memorizing the relationship of polarity to direction of current flow, which is as follows: if, when looking at one end of the coil, the current is flowing in a clockwise direction, then the end of the coil which we are looking at is a south pole.

The strength of a magnetic field produced in this manner is directly proportional to the **magneto motive force** applied, which is proportional to the number of turns of wire, and to the current strength, i.e. to the amperes × turns. The magnetic lines of force in a solenoid produce what is usually referred to simply as a **magnetic flux,** and the density of a magnetic flux is measured in terms of so many lines of force per sq. cm. of cross-sectional area.

The presence of iron, or other magnetic material, within the magnetic field, will result in a further distortion and concentration of lines of force through the material, since iron is by several hundred times a better conductor of magnetic lines of force than is air. In producing a flux in a magnetic circuit, there is a certain opposition to be overcome by the applied magneto motive force (M.M.F.), and this opposition is termed the **reluctance** of the circuit. The reluctance, or magnetic resistance, of a piece of material is proportional to its length, cross-section, and permeability, and is thus seen to be analogous to the ohmic resistance of a wire to the passage of an

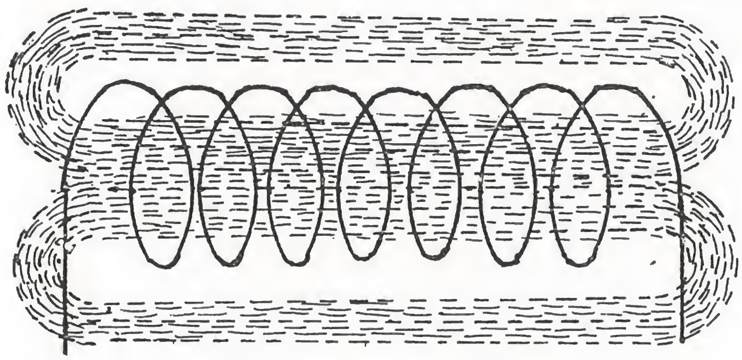


FIG. 5

electric current. It will be noted that the relationship between these terms, viz. $\text{Flux} = \frac{\text{M.M.F.}}{\text{Reluctance}}$, is identical with Ohm's law for electrical circuits, viz. $\text{Current} = \frac{\text{E.M.F.}}{\text{Resistance}}$.

The existence and shape of a magnetic field may be rendered visible by a very simple and beautiful experiment (Figs. 6 and 7). Take an ordinary sheet of glass and support it near its edges in a horizontal plane. On the upper surface of the glass sprinkle evenly a thin layer of iron filings. Now bring a solenoid of wire close up to the underneath surface of the glass. On sending a current through the wire it will be observed that the iron filings will move on the plate, and arrange themselves to form a pattern indicating the direction of flow of the magnetic lines of force. The exact pattern formed will, of course, depend on the disposition of the solenoid relative to the glass. The movement of the filings may be assisted by gently tapping the glass with a pencil.

We have already seen that electrons have associated with them an electric field, and that when an electron is in motion, the movement of its electric field produces a corresponding magnetic field. This statement is equally true whether we are speaking of (*a*) the movement of electrons from atom to atom along a wire, or of (*b*) the movement of an electron in its orbit round the proton or nucleus of an atom. In the case of (*a*) we have already referred to the production of the magnetic field round a wire carrying a stream of electrons. In the case of (*b*) it will be seen that the resulting magnetic field will be associated only with the single atom under consideration. Thus we are forced to the conclusion that each atom has in itself the properties of a tiny magnet. Why, then, does not a mass, representing a large number of atoms, exhibit always the properties of a **magnet**? Considering only the case of iron, it is assumed that each atom is a magnet with a north and a south pole, and that in a mass of iron all

these tiny magnets are normally so thoroughly mixed up, the south pole of one atom lying towards the north pole of the next atom, that all their tiny fields are mutually neutralized, and the whole mass thus exhibits no magnetic properties.

In its natural state, iron and the ores of iron normally exhibit no magnetic qualities. In certain localities, however, deposits of iron ore may be found which possess natural magnetic qualities, and these will be retained by the ore even after quarrying. Such an ore is Magnetite (Fe_3O_4), which is found in Spain, Sweden, North America, Asia Minor, etc., although not always in a magnetized condition. The reasons for the phenomenon are obscure, but are probably associated with the disposition of the ore in the ground, in relation to the magnetic lines of force of the earth, which itself behaves as a large but weak magnet.

The magnetic properties of iron or iron ores are destroyed by great heat, such as is encountered in a smelting furnace, although a much lower degree of heat may be effective. The magnetic properties may be restored by bringing the specimen under the influence of a powerful magnetic field, such as is produced by the passage of a strong electric current round a solenoid of wire, or by a strong permanent magnet of steel. A bar of steel, if held so that its axis lies along the natural lines of force of the earth, and tapped with a hammer, will acquire magnetic properties to a certain degree. Conversely, a bar magnet held across the natural lines of force of the earth, and tapped with a hammer, will lose some, or all, of its magnetic properties. Several cases have been known of the steel structure of an aircraft becoming powerfully magnetized due to the machine having encountered a lightning discharge whilst in flight. Incidentally, one of the effects of such an occurrence is to render the aircraft's compass totally ineffective as a navigating device.

When a bar of iron is magnetized it is believed that the constituent atoms have become arranged orderly, so that all the south poles point towards one end of the bar and all the north poles towards the other, so that the resulting magnetism of the bar is the summation of all the individual magnetic fields of those constituent atoms which have responded to the "lining up" process. Although iron will readily become strongly magnetized, it will just as readily lose its magnetic properties when the magnetizing force is removed. Yet there will generally be a certain small amount of residual magnetism left after the magnetizing force is removed, depending principally on the quality and purity of the iron.

The following list shows the relative susceptibilities of different substances to magnetic fields—

Oxygen . . .	17·5	Water . . .	96·6
Air	3·4	Sulphur . .	118·0
Hydrogen . .	0·1	Bismuth . .	1967·0
Zinc . . .	74·6		

It should be noted that magnetic substances exhibit a certain disinclination to become magnetized or demagnetized, i.e. the effect produced will lag slightly behind the cause, and this "lagging behind" property is known as **hysteresis.** The purest soft iron (i.e. Swedish) offers the least resistance to magnetic lines of force, i.e. is the most **permeable,** and it also exhibits the lowest hysteresis effects. Steel, on the other hand, is not nearly so permeable, and exhibits much greater hysteresis effects. For these reasons, soft or well annealed iron is suitable for electro-magnets, transformers, and other forms of apparatus which depend for their operation on rapid reversals of magnetic properties. Similarly, steel is suitable for machines requiring a strong and permanent magnetization. The

presence of certain other metals, such as cobalt, tungsten, nickel, etc., in steel greatly enhances the strength and permanence of a magnet produced from such material.

If two magnetized pieces of steel are placed with the north pole of one

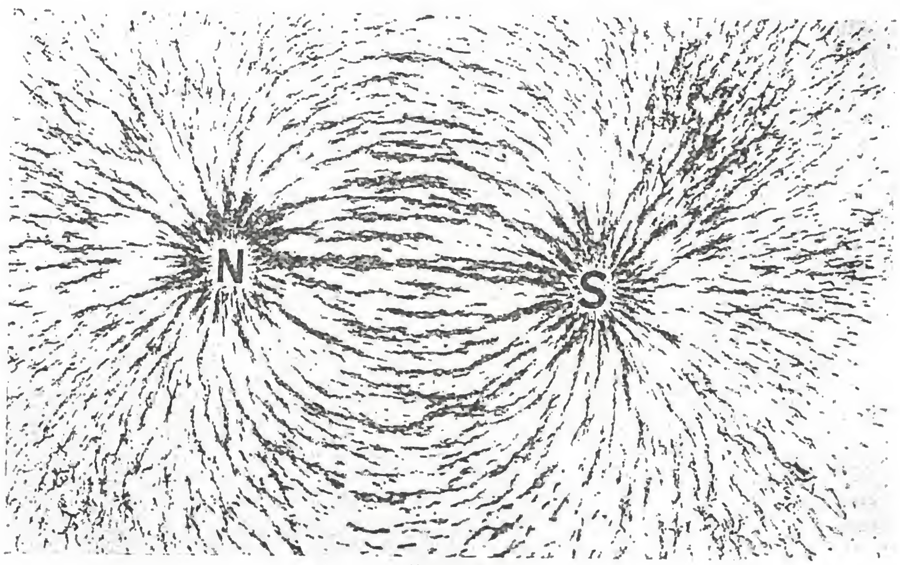


FIG. 6

near the south pole of the other, a strong attractive force between the two will be observed (Fig. 6). Similarly, a strong repulsive effect will be observed when the north pole of one magnet is brought into proximity with the north pole of the other (Fig. 7). From this phenomenon is evolved the law that "like poles repel and unlike poles attract."

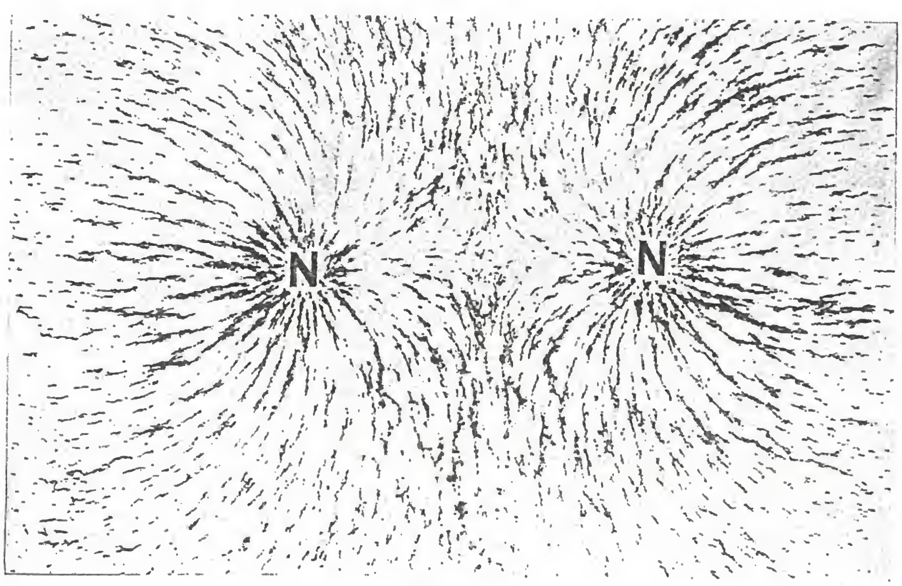


FIG. 7

Whilst iron is strongly attracted by a magnet, nickel and cobalt are also attracted to a feeble extent, and many other substances to a very much lesser extent. Such substances are referred to as having Paramagnetic qualities. Paramagnetism of atoms or ions is an indication of a lack of symmetry—and so of magnetic balance—of the electron orbits.

Copper and bismuth, on the other hand, are feebly repelled by a magnet, and a number of other substances also exhibit the same property, known as Diamagnetism, to a very feeble extent.

Whilst paramagnetism is a particular property of electronic systems possessing unbalanced electronic orbits capable of changing their orientation, diamagnetism is common to all matter.

We have already referred to the fact that when a current of electricity flows along a wire, concentric circles of magnetic lines of force surround the wire. If the current of electricity in the wire is suddenly changed in value, we shall find that there will be a corresponding change in the value of the magnetic field which surrounds the wire. Conversely, if the magnetic field surrounding a wire is suddenly changed in value, there will be a corresponding change in the value of the current flowing in the wire. This reciprocal reaction between magnetic fields surrounding wire and the current flowing in a wire is the basis of design of many forms of electrical machinery, such as dynamos, motors, alternators, transformers, etc., and we will examine this phenomenon a little more closely.

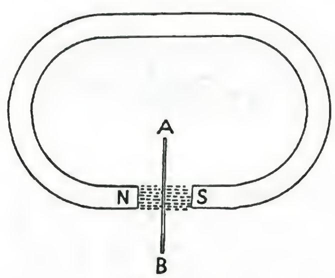


FIG. 8

Suppose that AB in Fig. 8 represents a wire lying in the magnetic field between the north and south poles of a horseshoe magnet. If this wire is moved horizontally backwards and forwards between the poles there will be no effect on the wire because it is "sliding" along the lines of force. It is not cutting through them, and the magnetic field round the wire is not changing in value. If, however, the wire were to be raised and lowered in a plane vertical to the surface of the paper, it would cut through the lines of force, and this would result in an E.M.F. being produced in the wire, i.e. one end of the wire would be raised to a higher potential than the other end, and a current of electricity would flow in the wire if the circuit were completed. Elaborating this process a little further, we will suppose that the poles of our horseshoe magnet are opened further apart, and a separate bar magnet, or piece of iron, introduced between the poles, but not touching them, so that two gaps are produced, one at each end of the bar, with a strong magnetic field in each gap, and our length of wire is now replaced by a loop of wire AB capable of being rotated about the axis CD (see Fig. 9). It will now be noted that when this loop of wire is rotated there are two sections of the loop which will cut through lines of force as they pass the poles of the magnet, and these sections are connected together at one side, and the ends brought out at the other. The rotary motion of such a loop of wire through the magnetic fields could be maintained indefinitely, and the two open ends would supply an E.M.F. which could be utilized to cause current to flow in an external circuit. Such is the basic design of the dynamo and alternator. The E.M.F. produced in this case would not be a steady E.M.F., but would rise and fall in value as the limbs of the loop approached and receded from the magnetic fields, and would change in polarity as the limbs of the loop passed from one magnetic field to the other, so that the resultant E.M.F. would be an

alternating E.M.F., rising from zero to a maximum value in one direction, then falling again to zero and rising to a maximum value in the opposite direction, and the resultant E.M.F. would be the sum of the E.M.F.s produced in the two limbs of the loop.

In practice, of course, this arrangement is elaborated by increasing the number of turns of wire in the loop, increasing the number of loops and increasing the number of poles. The E.M.F. produced from such machines may, if desired, be "commuted," or rendered unidirectional, by bringing the ends of the loop to a commutator fixed to the shaft, the external circuit being connected to this by means of fixed brushes which rub on its surface as it rotates. The brushes make contact with each loop, through appropriate sectors of the commutator, only during that part of the revolution during which the loop is cutting the maximum number of lines of force, passing then to the next following loop connections. The E.M.F. produced in this manner is directly proportional to the rate of cutting lines of force, and it will be at once apparent that this will be affected by (*a*) speed of rotation; (*b*) strength of field, i.e. number of lines of force per unit area; (*c*) length of "active" conductor, i.e. length of conductor actually cutting lines of force, and neglecting length of dead end connections. The direction of flow of the resultant current may be most conveniently remembered by **Fleming's rule**, which is shown in Fig. 10.

Using the right hand, and holding the thumb and first two fingers so that each is perpendicular to the plane containing the other two, the three directions are given by the rule—

Thumb shows direction of motion of conductor.

First finger shows direction of lines of force.

Second finger shows direction of E.M.F.

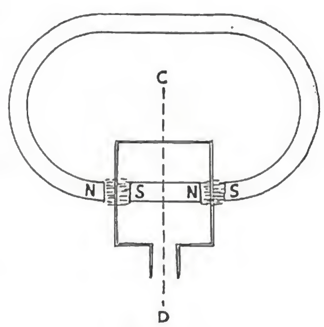


FIG. 9

In general, it is true to say that a machine designed to produce an E.M.F. by the application of mechanical force to rotate conductors in a magnetic field is capable of the reverse function, i.e. it will produce mechanical force when an E.M.F. is applied to its conductors; thus a dynamo is capable of operating as a motor, and *vice versa*. In certain cases, peculiarities of design will, however, defeat this object and the machine will only operate to the end for which it has been designed.

Mechanical force is required to move a conductor generating an E.M.F. and a current through a magnetic field, because the current flowing through the conductor sets up a flux around it, which reacts on the flux which is being cut, in such a manner as to oppose the motion of the conductor. This fact is expressed in **Lenz's law** which states that "in a case of mutual motion of circuits, or circuits and magnets, the induced effects will always be such as to oppose the motion."

We have referred to the method of producing an induced E.M.F. by means of a stationary magnetic flux and a moving conductor, but similar results may also be obtained by means of (*a*) a moving flux and a stationary conductor; (*b*) a variable flux and a stationary conductor; (*c*) a variable flux and a moving conductor.

We must now consider the case where a conductor is cut by its own lines of force, i.e. when the lines of force associated with its current vary in number due to the current changing its strength, when an E.M.F will

be induced in the conductor. This can only occur, of course, when the current is either increasing or decreasing in value.

When we start a current in a wire, the current produces a field, which reacts upon the current, by setting up an opposing E.M.F. which delays its growth, the result being that it takes time to cause a current to reach its full value. Similarly, when the current is switched off, the magnetic field is destroyed, and an **induced current** in the same direction as the one cut off is established. These effects are known as **self-induction.** We know that if we apply a steady pull to a heavy body, say a garden roller, we do not at once produce in it the full velocity due to that pull. Time is required to get up speed. Moreover, when the speed has been acquired, a reversed force will not at once bring the heavy body to rest, and time is again required to destroy the motion. This is due to the inertia of the garden

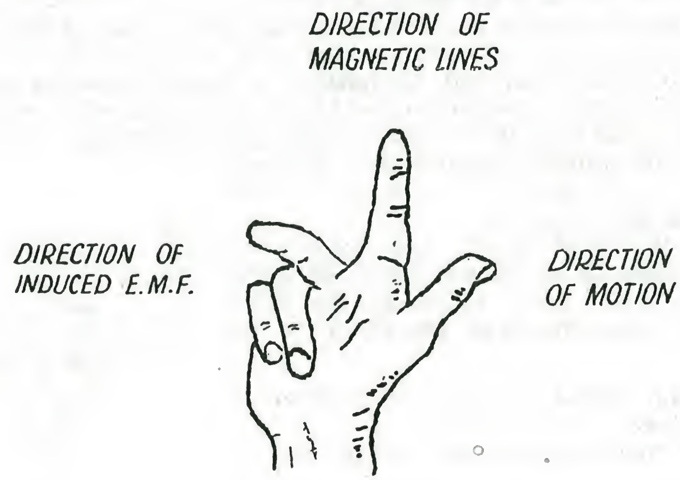


FIG. 10

roller and there is an exactly similar inertia effect in connection with conducting circuits, this effect being known as the Inductance of the circuit. As a consequence of these facts, it is found that when we switch a current on, no spark is observed, but when a current is switched off a heavy spark may be obtained at the point of break, this being due to the storage of energy in the magnetic field, which, on collapse, produces the so-called extra current in the same direction as the one switched off. The magnitude of this extra current will vary with the strength of the magnetic field which is broken down. Thus, a plain conductor will have associated with it a comparatively weak magnetic field, which can only produce a weak "extra current" on breakdown, but a circuit containing coiled conductors (solenoid) will have a much stronger magnetic field, which again will be very greatly increased where an iron core is employed, and the extra current at breakdown of such a field will be very considerable, often largely exceeding in value that of the original steady current.

The diagrams shown in Fig. 11 are arranged from left to right in order of their inductance, from nil on the left to maximum on the right. The foregoing explanation will supply the reasons for the provision of special switch gear, etc., in circuits to transformers, motors, etc.

Fig. 11A illustrates a conductor doubled back upon itself in such a way that the inductance of one half of it is neutralized by the inductance in the other half; 11B is a plain straight conductor; 11C is a conductor having one

or two loops in it; 11D is a conductor having a large number of loops; and 11E is a conductor with a large number of loops wound upon an iron core; and 11F is a conductor with a large number of turns wound up one arm of a closed iron circuit.

The practical unit of self-inductance is the **henry.** A coil has an inductance of 1 henry when, if the current through it changes at the rate

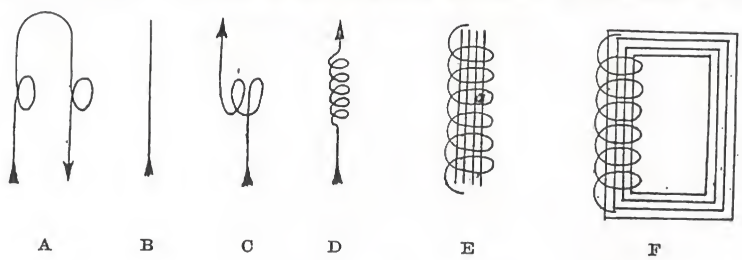


FIG. 11

of 1 ampere per second, an E.M.F. of 1 volt is induced. From this it will be seen that—

$$\underset{\text{(volts)}}{\text{Induced E.M.F.}} = \underset{\text{(amperes per second)}}{\text{Rate of change of Current}} \times \underset{\text{(henrys)}}{\text{Inductance}}$$

We now come to the last electrical unit with which we shall be concerned, viz. the **farad.** Suppose that two insulated metal plates, *A* and *B*,

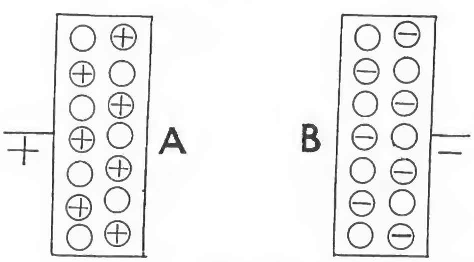


FIG. 12

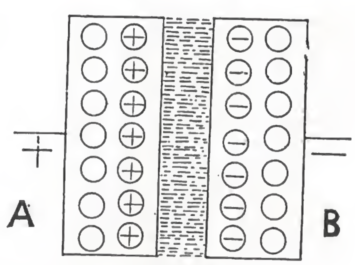


FIG. 13

some distance apart, are connected to D.C. mains or a battery. Then, the the plates being too far apart to influence one another, they will have the potentials of the positive and negative terminals of the mains or battery, and *A* will consist of neutral molecules and positive ions, i.e. molecules deficient of electrons, whilst *B* will consist of neutral molecules and negative ions, i.e. molecules with excess electrons. The plates have "charges," and potentials corresponding to those charges. Now, if these plates are brought near together, an electric field is set up through the dielectric between them, and this dielectric is strained so that there is an urge for the electrons and positive charges to separate from the molecules, and they try to move towards the positive and negative plates respectively. The effect of this strain in the dielectric is to reduce the potential difference between the two plates, and this loss of P.D. has to be made up from the mains or battery. Thus a momentary flow of electrons is produced through the mains until the P.D. of the plates is restored. The magnitude of the charges upon the plates will obviously govern the strength of the electric field and the consequent degree of strain in the dielectric, and the greater the strain in the dielectric the greater will be the amount of electrical energy stored up in the device, which is known as a **condenser.**

We have a parallel in the case of an ordinary steel spring, where the greater the strain in it, the greater the amount of stored up mechanical energy, which will be liberated by the uncoiling of the spring. If our condenser is disconnected from the mains it will retain its electrical charge, which will be liberated into a circuit connecting the two plates together.

A condenser is said to have a capacity of 1 farad when a charge of 1 coulomb (one ampere flowing for 1 sec.) produces a P.D. between the two plates of 1 volt. A small condenser may, perhaps, hold an equal number of coulombs to a large one, but the P.D. (or E.M.F.) must necessarily be higher. Increasing the area of the plates, or decreasing the thickness of the dielectric, will increase the capacity of a condenser.

Different dielectrics act differently as regards the inductive action between the plates. For instance, mica will suffer a greater electric strain than air, and if mica be substituted for air in a condenser, a greater charge must be given to produce the same E.M.F. The mica condenser, therefore, has a larger capacity, other things being equal. This property of the dielectric is termed its **specific inductive capacity,** or dielectric constant.

The following are puncturing voltages for various dielectrics between plates 1 mm. apart—

Dielectric	Puncturing Voltage	Corresponding Sparking Distance between Plates in Air
Crystal glass	28,500	9 mm.
India-rubber	40,000	13 mm.
Ebonite	50,000	14 mm.
Mica	60,000	20 mm.
Oil (vaseline)	7,000	2·5 mm.

The above values will be influenced by the shape of the electrodes, the duration of application, and the frequency and wave form of the applied voltage (if alternating).

If several condensers are joined in series, the combined capacity is given by the equation

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \text{ etc.}$$

Where several condensers are joined in parallel, the total capacity is obtained by adding together their individual capacities.

It will be noted that these formulae are the reverse of those used when calculating resistance.

When a condenser is discharged by short-circuiting the plates, the flow of current does not consist of a single unidirectional surge of current, but is of an oscillatory character. The first surge of current appears to be carried by its impetus beyond the point necessary to establish equilibrium, and there is a diminishing flow backwards and forwards until equilibrium is established. The frequency of the discharge is affected by the magnitude, not only of the condenser capacity, but also of the inductance in circuit, being determined directly as the square roots of those quantities, and assuming that any pure resistance present is small enough to be neglected. The combination of capacity and inductance in a circuit with negligible resistance produces an **oscillatory circuit,** but if the resistance present is too high in value the oscillatory nature of the discharge is destroyed, and a gradual leak only is produced.

CHAPTER IV

ELECTRICAL EQUIPMENT OF AIRCRAFT

Accumulators

As it is often necessary to operate some part of the electrical equipment of an aircraft when the dynamo is not functioning, an alternative source of current has to be provided, and this normally takes the form of an "accumulator." A supply of current may be obtained from various kinds of voltaic cells, which may be divided into two main classes according to their principle of operation. In the first class the electrical energy is obtained solely as a result of chemical reaction in the cell, involving the wastage of one of the constituents of the cell. The action is therefore direct, and cells operating on this principle are termed **primary cells,** the commonest example being the ordinary Leclanché cell.

As primary cells, or batteries of primary cells, are now seldom used on aircraft we will proceed at once to deal with the second main class, with which we shall be intimately concerned. In this class, electrical energy is first supplied to the cell, and produces certain chemical changes in the constituents of the cell. These chemical changes are capable of reversal, and during this reversal the cell will itself supply electrical energy. The action is therefore indirect and reversible, and is considered as a secondary action. Cells of this type are known as **secondary cells** or "accumulators." Common examples of secondary cells are those of the lead-acid type, and of the nickel-iron-alkali type. It is a common fallacy that accumulators are devices for accumulating and storing electrical energy, but it will be obvious that what really happens is that the electrical energy supplied to the accumulator is converted into chemical energy, and is stored in that form. On completing the external electrical circuit of an accumulator a current will flow from it as long as the chemical action persists, i.e. until the constituents of the cell have regained their initial state.

A secondary cell consists essentially of two metal plates immersed in a liquid, which is known as the electrolyte. The commonest form of accumulator is that known as the "Lead-Acid" type, in which the plates are of lead, and dilute sulphuric acid is used as the electrolyte. During charging, one plate (the anode, or positive plate) is connected to the positive terminal of a source of direct current supply of suitable voltage, the other plate (the cathode, or negative plate) being connected to the negative terminal. The current thus flows, during charging, through the electrolyte from the anode to the cathode. During discharge, however, the current flows through the electrolyte from the cathode to the anode. An accumulator constructed with plain lead plates would, however, have very small capacity, as the chemical reactions occur only on the surface of the plates, and do not penetrate to an appreciable depth. The capacity would gradually increase with the number of times it was charged and discharged, as each successive cycle of operations would increase the depth of active surface material.

In order to speed up the process, and to give the accumulator an initial high capacity, the surfaces of the lead plates are specially prepared. There are two principal methods of preparing the plates, each named after the original inventor. One type is known as the *Fauré* or "pasted" type, and the other as the *Planté* or "formed" type. Plates of the *Fauré* type are made in the form of a grid, the interstices of which are filled under hydraulic

pressure with a paste made from certain lead oxides which readily lend themselves to the chemical processes which take place during charging and discharging. The paste used for the positive plates is usually red lead (Pb_3O_4) mixed with dilute sulphuric acid (H_2SO_4), and the paste for the negative plates consists of litharge or lead monoxide (PbO) also mixed with dilute sulphuric acid. The mechanical strength of the lead grid into which the paste is forced is usually increased by the admixture of 5 per cent to 10 per cent of antimony. Accumulators constructed on the Fauré principle are very robust but suffer from the disadvantage that high rates of charging or discharging tend to disintegrate the plates.

In the Planté principle of construction the positive plates are made from pure lead, and are deeply grooved to give a maximum surface area. Such plates are "formed" by immersing them in a forming bath and passing a current between them until a fairly thick film of lead peroxide (PbO_2) is formed over the whole surface of the plates. No paste is used with these positive plates, the active material being produced from the pure lead of the plate by chemical action during "formation." The negative plates in a Planté cell are usually of the pasted type and similar to those used in the Fauré cell. Planté type plates are not so mechanically strong as Fauré type plates, but they can be successfully charged and discharged at higher rates than similar sized plates of the Fauré type.

In order to grasp the main principles of operation of an accumulator, some explanation of the complex changes produced by charging and discharging is necessary. Before the initial charge of a new cell, the active material of the positive plate consists of red lead (Pb_3O_4) and the negative plate of lead monoxide (PbO). The plates are immersed in dilute sulphuric acid and a current is passed from the positive to the negative plate. The electrolyte is thereby ionized, oxygen being liberated at the positive plate and hydrogen at the negative plate. Both of these gases are very strongly active when in the nascent ("just born") condition, and their action on the paste in the plates may be represented by the following equations—

POSITIVE

$$Pb_3O_4 + O_2 = 3\,PbO_2$$

NEGATIVE

$$PbO + H_2 = Pb + H_2O$$

We thus see that the red lead of the new positive plates takes up oxygen to form lead peroxide, whilst the litharge of the negative plates gives up oxygen and is reduced to pure lead. The products of these chemical changes form very porous coatings on the plates, and the reactions go on so long as material is exposed to them. In time, of course, the products of the reactions completely cover the remainder of the original active material, and the action stops. Where the charging operation is carried out slowly, the formation of a thicker surface covering of porous material is favoured, and, because a larger surface area is thereby produced, a larger amount of energy may be stored up. The depth of porous active surface material in a well-cared-for accumulator will increase with age, and therefore its capacity will increase, until the time comes when the plates begin to disintegrate.

On discharging an accumulator by connecting the plates externally, the flow of current through the electrolyte is in the opposite direction, and we therefore have oxygen liberated at the negative plate, and hydrogen at the positive plate. The ensuing chemical reactions are very complex, but may be regarded as occurring in two stages simultaneously. At the

positive plate, the hydrogen first reduces the lead peroxide to lead monoxide, the latter then being immediately transformed into lead sulphate, thus—

$$\underline{PbO_2} + H_2 = H_2O + PbO$$
$$PbO + H_2SO_4 = H_2O + \underline{PbSO_4}$$

Thus the peroxide, which is a deep chocolate colour, is gradually removed and the plate becomes partly coated with white lead sulphate. At the negative plate, the oxygen first combines with the lead to form lead monoxide, and the acid of the electrolyte then converts the latter into white lead sulphate, thus—

$$\underline{Pb} + O = PbO$$
$$PbO + H_2SO_4 = H_2O + \underline{PbSO_4}$$

The lead sulphate thus formed on both plates is soft and soluble until the cell is discharged down to 1·8 volts on closed circuit. If discharge is continued beyond this limit the sulphate becomes hard and insoluble, and adversely affects the subsequent working of the cell.

When the cell is fully charged the electrolyte (dilute H_2SO_4) has a specific gravity of 1·220 to 1·270. The specific gravity falls during discharge to about 1·150. This weakening of the electrolyte is due to the breakdown of a certain proportion of the H_2SO_4 to form lead sulphate and water.

The chemical changes associated with the second and subsequent charging operations differ materially from those associated with the initial charge as outlined above. After the initial charge and discharge operations are completed, subsequent charging operations again produce oxygen at the positive plate and hydrogen at the negative plate, but both of these plates are now coated with $PbSO_4$. The reaction at the positive plate now may be represented by the following reaction

$$PbSO_4 + O + H_2O = PbO_2 + H_2SO_4$$

whilst that at the negative plate may now be represented by

$$PbSO_4 + H_2 = Pb + H_2SO_4$$

From these reactions it will be noted that both plates are brought back to the same chemical state as that obtaining before discharge, accompanied by the formation of H_2SO_4, which goes to raise the specific gravity of the electrolyte.

On open circuit, a fully charged cell should show about 2·2 volts. This voltage will fall as the cell is discharged, the rate of fall being dependent on the rate of discharge. Comparative curves showing the fall of voltage on discharge at the 10 hour rate, and the rise in terminal voltage during charging at the same rate are given in Fig. 14. The similarity in form of the voltage characteristics on charge and discharge is at once apparent from the curves.

The capacity of an accumulator is its output expressed in ampere-hours, i.e. the product of the current (amperes) and the time (hours) for which that current can be taken from a fully charged cell, up to the time the terminal voltage has fallen to 1·8 volts on load. The capacity of a cell is normally based on the 10-hour rate of discharge, i.e. the current which will discharge the cell to 1·8 volts in 10-hours. If this rate of discharge is reduced, the apparent capacity will be somewhat increased, and similarly if the rate of discharge is exceeded, the apparent capacity will be reduced.

Considering a 20 ampere-hour accumulator, we shall find that its capacity at different rates would be—

10-hour rate	=	20 amp. hours	=	2 amps.	×	10 hours
5 ,, ,,	=	15 ,, ,,	=	3 ,,	×	5 ,,
1 ,, ,,	=	10 ,, ,,	=	10 ,,	×	1 ,,

From the foregoing it will be observed that the capacity of a cell is not a constant quantity, but depends on the amount of active material in the plates, and the rate of discharge. The operating temperature also has a large influence on the capacity, which will fall with a fall in temperature. The capacity of a cell based on the 10-hour rate is its actual

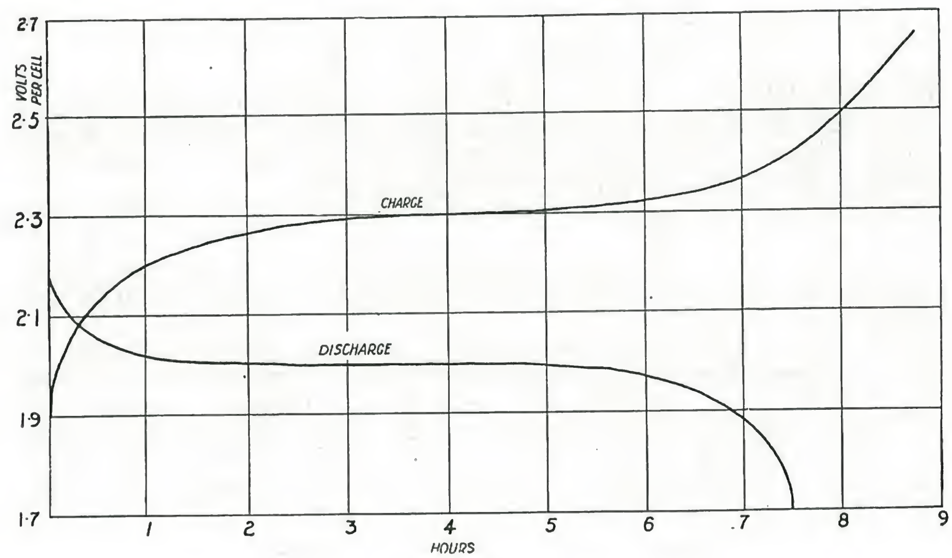


Fig. 14

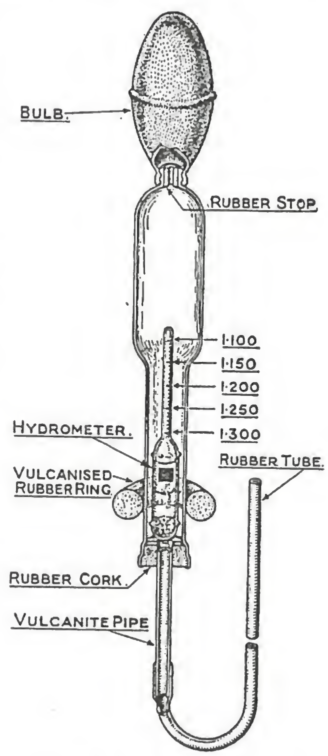
capacity, and this is approximately half of its capacity when based on "ignition" rating.

A cell in good condition should yield on discharge from 85 per cent to 90 per cent of the energy (ampere-hours) expended in charging it. The useful life of a cell for aircraft purposes may be taken as terminated when its capacity has fallen by about 40 per cent. A cell designed for heavy rates of discharge is usually provided with thin plates, since their capacity does not fall away so rapidly as with plates of average thickness, when the 10-hour rate of discharge is exceeded. Cells with very thick plates are only intended for slow rates of discharge, and they may be considerably damaged, or their effective life reduced, if subjected to any discharge above the 10-hour rate.

To obtain cells of large capacity it is necessary to increase the area of the plates, and in order to facilitate manufacture and handling this is normally accomplished by using several small plates in place of one large one. Thus a cell may have several positive and several negative plates, and in order to take advantage of both sides of each plate, the positive and negative plates are interleaved alternately, the plates being formed with lugs which extend upwards and are connected to bus-bars, all the positive plates to one bar and all the negative plates to the other bar. It is normal practice to have one more negative plate than positive, so

that the two outside end plates are always negatives, and both sides of every positive are opposite a negative and therefore active. This arrangement is necessary, since during the chemical actions of charging and discharging positive plates tend to buckle readily if the active material of the plate is acted on from one side only.

The plates are prevented from touching by separators, which are constructed either of corrugated celluloid, ebonite, or grooved partitions of specially prepared wood. In certain cases glass tubes are used as separators and, where glass containers are used, grooves and ribs moulded on to the interior walls of the container are common. Celluloid separators are largely disappearing, since after they have been in use some time they tend to promote frothing towards the end of the charging operation, when the plates are gassing freely. Separators must be designed so that free circulation of the electrolyte is permitted. Restriction of this circulation will cause unevenness of density of the electrolyte, resulting in uneven discharge and promoting buckling of plates and shedding of active material. Plates should not rest on the bottom of the container, but a liberal space should always be left for the collection of sediment. Sediment at the bottom of the container consists mainly of active material which has fallen from the plates, and this will short-circuit the cell if it bridges the gap between the plates.



* FIG. 15. SYRINGE HYDROMETER

The electrolyte in ordinary types of accumulator cells should consist of pure brimstone sulphuric acid, having a specific gravity of 1·800 to 1·900, diluted to the correct density by means of distilled water. The strong acid should always be added very slowly and very carefully to the water, and not *vice versa*, and mixing should be done in a glazed earthenware, glass, or lead vessel. No other vessel should be used for this purpose owing to the introduction of harmful impurities by the action of the acid on any other common form of metal container. The usual proportions are $3\frac{1}{2}$ to 4 parts of water to 1 part of acid, but the exact specific gravity must always be measured by means of an hydrometer. (Fig. 15.)

Considerable heat is generated during the process of dilution, and the mixture must be allowed to cool before using the hydrometer, or filling into a cell. The specific gravity of the dilute acid should be in accordance with the makers' instructions for the particular type of cell which is being filled. Hydrometers are of various types, but probably the best type for use with small portable cells consists of a hydrometer proper which is enclosed in a glass outer shell having a rubber bulb at the upper end and a short rubber tube at the lower end. By means of the bulb, acid may be drawn up through the tube into the shell and the hydrometer thus floated. After taking a reading on the instrument the acid may be returned to the cell.

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The first charge given to an accumulator cell is a special charge required to complete the "formation" of the plates, and to bring them to the required condition for normal working. If this initial charge is improperly carried out, serious damage may be done to the cell. If the full capacity and normal life are to be obtained from an accumulator cell, the makers' instructions given for first charge procedure must be carried out in every detail. As soon as the voltage of any accumulator falls to 1·8 volt per cell on closed circuit, it should be recharged immediately. A cell should never be allowed to stand for any appreciable period in a partly discharged state, if sulphation troubles are to be avoided. Loss of electrolyte should be made good with new dilute acid (1·220 sp. gr.) if the loss was sustained by spilling, or by distilled water if the loss was occasioned by evaporation. Free use should be made of the hydrometer to check the actual specific gravity of the electrolyte, but readings should always be taken immediately after charging, when the specific gravity should be 1·250 or as advised by the makers of the accumulator.

The use of weak electrolyte will result in loss of capacity, and will promote sulphation. The use of too strong electrolyte will also promote sulphation, local chemical action, self-discharge, and possibly damage to the container, if this is of celluloid, particularly if the specific gravity exceeds 1·300.

Particular care should be given to the correct connection of accumulators for charging. The positive terminal of the accumulator should always be connected to the positive terminal of the source of supply, and the negative terminal to the negative side. The polarity of the charging circuit may be determined in various ways, but the two following methods are common and convenient. The first method consists of pressing the ends of the two wires on to damp litmus paper (red or blue). The positive wire will turn blue litmus paper pink, and the negative wire will turn red litmus paper blue. The second method consists of pressing the two wires on to damp blue print paper. The negative wire will leave a white mark.

It is a good general rule, in the absence of makers' instructions, to charge cells at the 10-hour rate until the cells are gassing freely and the specific gravity of the electrolyte has reached a steady maximum as indicated above. It will usually be found necessary to include an adjustable resistance in circuit in order to be able to control the current, and an ammeter should always be included in the circuit in order that the amount of current passing may be ascertained. Such a resistance may take the form of a bank of lamps or an ordinary wire-wound resistance. In any case, the use of any resistance in circuit represents wastage of current and inefficiency in operation. It is better to control the current by connecting a suitable number of cells in series for charging. Where this is done, however, particular care has to be taken, where the cells are not all of equal capacity, to ensure that the charging rate is suitable for the smallest cell, and that small cells are not overcharged nor large cells undercharged. In order to determine the maximum number of cells which may be charged from a fixed voltage supply, 2·8 volts should be allowed for each cell. By cell is meant 1 unit of an accumulator. A 12-volt battery would contain 6 units or cells. Thus on ordinary 220 volt mains the number of cells which could be charged in series would be $\frac{220}{2{\cdot}8}$ or 78 cells or thirteen 12-volt batteries. If it is desired to charge a larger number of cells than can be arranged in one set connected in series, the cells may be divided into groups, all the cells in one group being connected in series, and the various groups in parallel. This arrangement, however, requires careful preparation if the cells are of

different types and capacities in order to avoid the dangers of overcharging some cells and undercharging others. All the cells in a group should be of approximately the same capacity, and each group should have its own ammeter and regulating resistance in circuit.

It is important to note that charging from mains can only be carried out where the supply is direct current. An alternating current supply is obviously useless for recharging accumulators. It is often found that where the number of cells to be charged at any one time is never large, but recharging operations are required at frequent intervals, it is more economical and efficient to install a motor-driven generator for the purpose. The motor, of course, would be of a type suitable for running off the mains, and in this case may be either a direct current or alternating current machine. The motor is used to drive a generator giving a direct current of suitable voltage for the general needs of the station, and 50–60 volts is often specified. The initial cost of a motor-driven generator may be a large item, but against this may be set the saving in cost of current otherwise wasted in large resistances or banks of lamps, as the overall efficiency of a motor generator is relatively high. For alternating current mains there are also available various devices for transforming the current to direct current suitable for battery charging purposes. Such devices include thermionic valve rectifiers, metal oxide rectifiers, synchronous motors fitted with commutators, etc.

The faults and troubles with lead-acid accumulators may be conveniently summarized as follows—

SULPHATION

Sulphation is the most common fault to which acid accumulators are liable. As a general rule, it is directly caused by neglect, as is shown by the following list of causes of this fault—

(i) Discharging an accumulator below 1·8 volts per cell.
(ii) Allowing a discharged or partly discharged cell to stand in that condition.
(iii) Persistent undercharging.
(iv) The use of too strong electrolyte.
(v) The use of too weak electrolyte.

By the term "sulphation," in connection with accumulators, is understood the formation of the white and almost insoluble sulphate of lead ($PbSO_4$). Whereas the normal chemical action of the cell during the discharge period involves the formation of lead sulphate, it should be remembered that this sulphate is soft and soluble during the period of discharge down to 1·8 volts per cell. This soluble sulphate turns hard and insoluble either after further discharge or from lack of recharging. The effect of bad sulphation is completely to prevent the chemical action taking place during charging and discharging, and therefore a cell in this condition is practically useless. In addition, the mechanical effect of this fault is to render the plates extremely brittle.

The successful treatment of cells for hard sulphation depends entirely on the amount of sulphation present. The procedure in removing the hard sulphate is as follows—

(i) Empty out the electrolyte and thoroughly wash out the cell with weak electrolyte.
(ii) Refill with weak electrolyte at a specific gravity of about 1·150.
(iii) Put on charge at one-quarter normal charging rate.
(iv) Allow the cell to gas steadily for a long period, since gassing tends to dislodge the insoluble sulphate which falls to the bottom of

the cell as a sediment. It may be necessary to continue this charge for a period of 100 hours or more.

(v) If this treatment is successful, empty out the electrolyte, thoroughly wash out all sediment with weak electrolyte and fill up with fresh acid at a specific gravity of 1·270 at 61° F.

(vi) Charge the cell at normal charging rate for a short period.

If the treatment outlined in the previous paragraph is not successful in removing all the insoluble sulphate, the cell may be carefully dismantled, and the plates taken out and carefully scraped or brushed in order to remove the hard sulphate. This operation requires considerable care since it is essential that the active material of the plates should not be disturbed in any way. The cell is then reassembled and placed on slow charge until it has been restored to normal condition as indicated in the previous paragraph. It must be noted that either form of treatment indicated above will tend to reduce the capacity and effective life of the cell.

Hydration

Hydration is the name given to the formation of white lead hydrate in lead-acid cells. This fault is caused by allowing water to remain in contact with the active material of the plates for an appreciable time. For this reason new accumulators should never be rinsed out with distilled water before filling with electrolyte for the first charge, since the tendency to hydration is thereby considerably increased. Hydration, like sulphation, considerably impairs the capacity of a cell, since it interferes with the chemical changes taking place during charging and discharging. Unlike sulphation, however, it is fairly easy to remove by prolonged charging. Cells exhibiting hydration are capable of restoration to a fairly good condition by following the procedure given in sub-paras. (iii) and (iv) under sulphation.

Buckling of Plates

This fault is generally due to excessive rates of charge and discharge. If the normal rate either of charge or discharge is considerably exceeded, the result is uneven chemical action in the active material of the plates. The chief reason for this is that the density of the electrolyte will not be uniform through the cell, as the normal circulation of the electrolyte is not sufficiently rapid to produce uniform conditions when heavy charge or discharge rates are employed. The effect of this uneven chemical action in the plates is to produce unequal strains, and the plates therefore buckle. The tendency of plates to buckle under the above conditions is greatly increased if the cell is overheated.

The only remedy for this fault is to dismantle the cell and to straighten out the buckled plates by pressing them gently between two pieces of board. It is clear that great care must be exercised in carrying out this operation as the plates are very brittle and there is considerable likelihood of loosening the active material, thus causing shedding.

Disintegration of Plates

This fault, like buckling of plates, is radical in its importance, and the capacity of any cell is very considerably impaired by shedding of active material. Amongst the many causes of disintegration are general neglect, prolonged overcharging, and long continued charging at current strengths much less than normal rate as indicated on the instruction labels. These causes, combined with abnormal heat, result in peroxidation of the lead grids and materially shorten the life of the cell. For continuous disintegration of plates there is no cure. Care should be taken to see that the

sediment collecting in the bottom of the container does not rise sufficiently high to short-circuit the bottom of the plates. The cell should be carefully shaken and the electrolyte and sediment poured out, the cell then being filled with fresh electrolyte and placed on charge at half-normal charging rate.

Internal Short-circuits

Any cell in which there is an internal short-circuit will not gas even after prolonged charging. When this occurs, the accumulator should be dismantled and the plates examined in order to ascertain the cause of the short-circuit. Short-circuits may be produced by neglect, resulting in hydration and severe sulphation. Also lead "trees" may be formed round the edges of adjacent plates, generally due to long continued charging at currents much below normal charging rate. These trees form more or less permanent short-circuits between two or more plates. High temperatures assist the formation of these growths and often cause expansion of the plates, thereby providing a further contributory cause of short-circuits.

Alkaline Type Batteries*

Another class of accumulator frequently met with on aircraft has an alkaline solution and either makes use of the elements nickel and cadmium or uses the elements nickel and iron for the active materials in the plates. These two distinct types of alkaline accumulators are being manufactured commercially. The former is generally known as the "NIFE" or Jungner type (see Fig. 16), while the latter is frequently referred to as the Edison type (see Fig. 17). The construction of both types is essentially the same in principle, the various manufacturers adopting differences in detail only. The active material is enclosed in steel tubes or pockets which are perforated with a very large number of minute holes over the whole of their surface, a number of these pockets being assembled into steel retaining frames to form complete positive or negative plates (see Figs. 18, 19, and 20). The required number of plates of the same polarity are mounted on collecting bolts with suitable steel spacing washers and terminal pillars, and are then firmly bolted together. The positive and negative plates are separated by means of ebonite rod insulators and the whole assembly mounted in a sheet steel container having welded joints, the terminals being brought through the cover in suitably insulated glands or stuffing boxes. This container is usually plated on the outside to prevent corrosion. The electrolyte used is a solution of pure potassium hydroxide having a normal specific gravity of about 1·19. In certain makes of cells a small quantity of other constituents is added, but these have no direct effect on the action of the cells. The strength of the solution, apart from evaporation, does not vary during either discharge or charge, and the electrolyte has no action on iron or steel, so that there is no possibility of internal corrosion.

It is seen that steel is used throughout in the construction of the cell; this is of very great advantage in view of the fact that all parts of the cell can be made with mathematical precision. The mechanical strength, durability, and robustness are much in advance of what can be obtained even in the best designs of lead cells—vibrations and shocks cannot dislodge the active material, with the result that there is a total absence of sludge and deposit—the steel plates cannot twist, buckle, break off or grow—the active material and other parts of the cells do not suffer any damage by overcharging, heavy discharging, or idleness.

* See Paper read before the Rugby Engineering Society by D. Kirkman, B.Sc. and F. Watson Mann, B.Sc. (27th January, 1932).

In both types the active material in the positive plates is essentially the same, and consists of nickel hydroxide, the action that takes place on disharge being a reduction from a higher form of nickel hydroxide to a lower form, and *vicc versa* on charge. In the nickel iron cell the active material in the negative plate is metallic iron which is oxidized on discharge

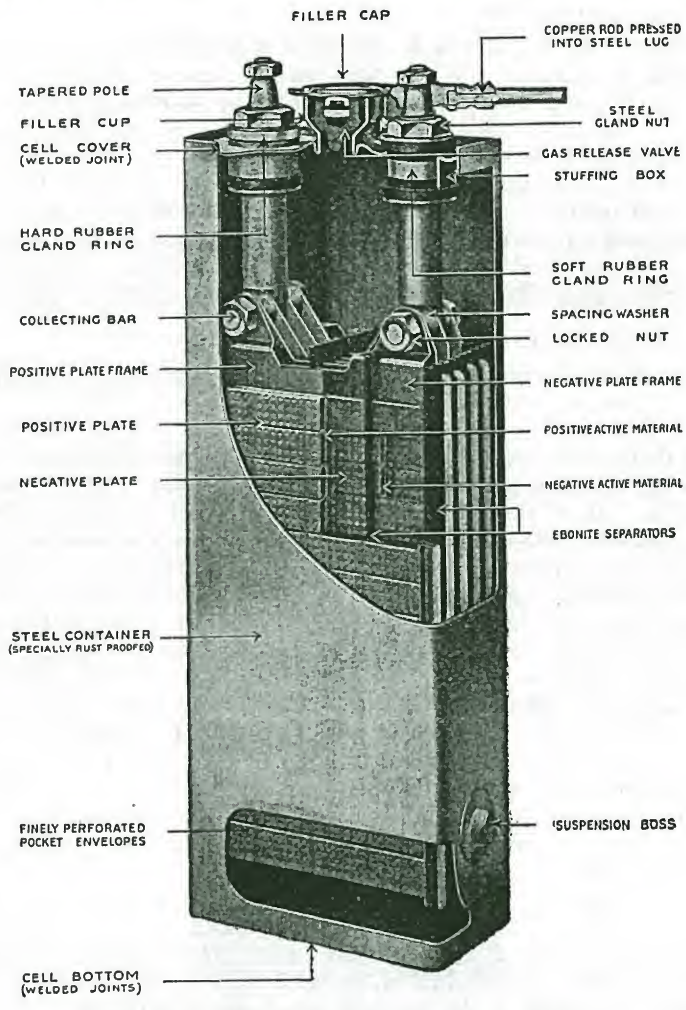


FIG. 16. "NIFE" NICKEL CADMIUM CELL

(*By courtesy of Batteries, Ltd.*)

to iron oxide (or hydroxide), and *vice versa* on charge, while in the nickel cadmium cell the iron is replaced with cadmium.

One of the biggest difficulties that had to be faced in the manufacture of alkaline cells was the high electrical resistance of the actual active materials, and this was overcome in various ingenious ways. In one example, the nickel hydroxide is mixed with flakes of pure nickel $\frac{1}{16}$ in. square and 0·00004 in. thick, the method being to have alternate layers of nickel hydroxide and flake nickel. Another method is that of mixing the nickel hydroxide intimately with a specially prepared flake graphite, which is chemically inert.

With the nickel iron cell the high resistance of the iron oxide formed on discharge is overcome by mixing the material intimately with about 6 per cent of yellow mercuric oxide. The resistance of the cadmium oxide

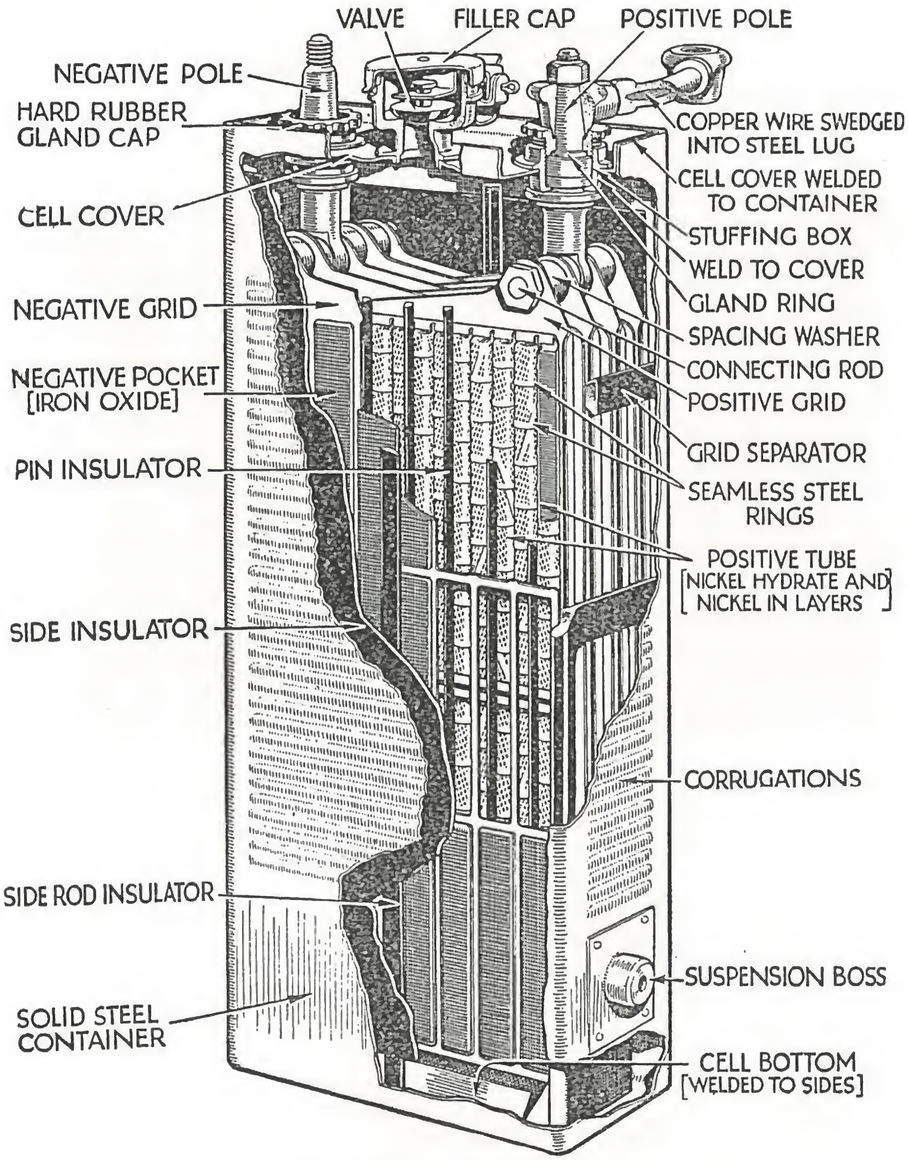


FIG. 17. EDISON NICKEL IRON CELL
(By courtesy of Edison Storage Battery Distributors, Ltd.)

in the nickel cadmium cell, however, is very much lower and it is unnecessary to add any special conducting material. There is, however, a tendency for the cadmium oxide to cake and lose porosity, and in order to overcome this the cadmium is mixed intimately with a small quantity of iron, the mixture retaining all the advantages of the cadmium and having none of the disadvantages of the iron. This mixture is of very special

interest, as both the constituents of the active material so formed take a useful part in the reactions of the cell, and it is the only case where a mixture of elements has proved a definite success as an accumulator electrode.

The theoretical discharge voltage of the cadmium negative plate is roughly 0·03 volts lower than that of the iron negative plate. This is, however, more than counterbalanced by the lower resistance of the cadmium plate; and the resulting voltage on discharge, except in the very

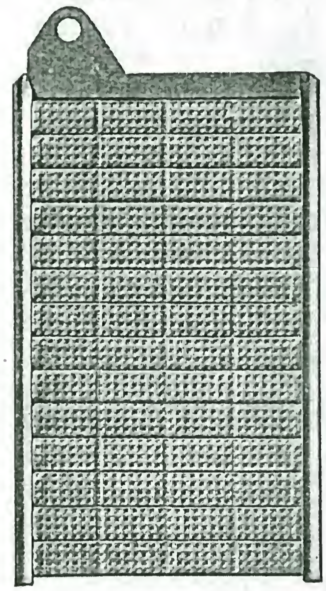


Fig. 18. "Nife" Positive or Negative Plate

(*By courtesy of Batteries, Ltd.*)

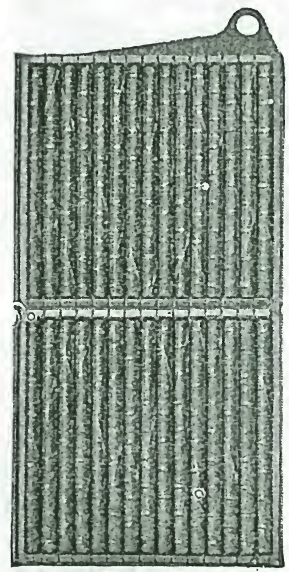


Fig. 19. Edison Positive Plate

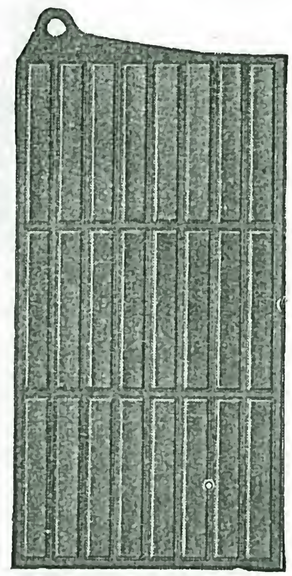


Fig. 20. Edison Negative Plate

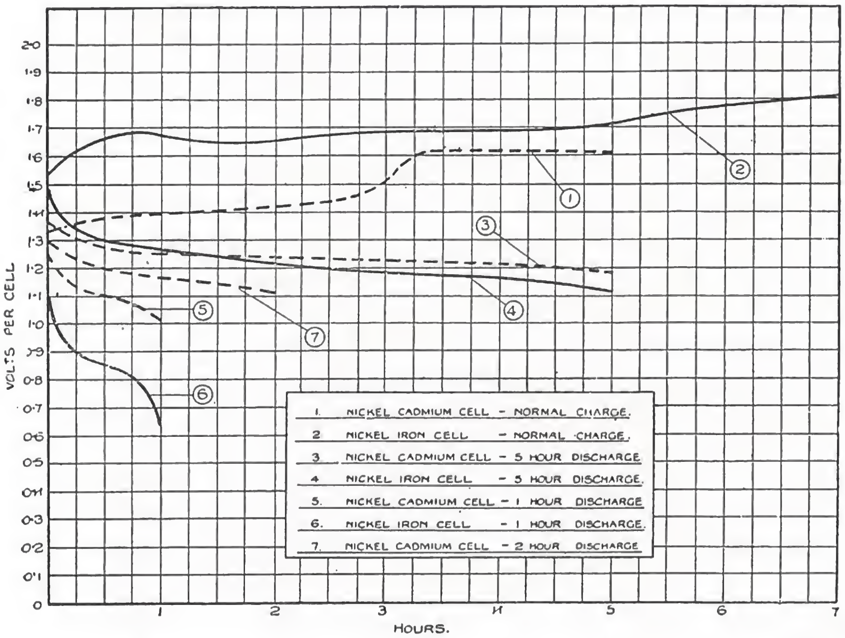
(*By courtesy of Edison Storage Battery Distributors, Ltd.*)

early stage, is actually slightly higher, this being particularly noticeable at higher discharge rates.

The charging voltage of cadmium oxide is very much lower than that of iron oxide, and this is one of the more important advantages of the cadmium plate. The voltage required for the conversion of cadmium oxide to cadmium (with a nickel hydroxide positive plate) is from 1·35 to 1·5 volts, while that for converting iron oxide to iron is 1·55 to 1·8 volts, these figures assuming approximately normal charging rates.

Another interesting point arises here. It would be thought on consideration of the above voltages that there would be a definite break in both the charge and discharge curves of a nickel cadmium cell having a negative plate consisting of a mixture of cadmium and iron. As the discharge potentials of cadmium and iron are very close together, the expected break in the discharge curve is smoothed over and is not apparent. On charge, however, there is a distinct break, which occurs after the cadmium oxide portion of the material has all been converted, and the position of this break is found to vary with the percentage of iron present in the plate (see Figs. 21 and 22).

The chemical reactions occurring in alkaline cells are extremely involved,



COMPARATIVE CHARACTERISTICS OF NICKEL CADMIUM AND NICKEL IRON CELLS

FIG. 21

and it is very difficult to give anything really conclusive, as various oxides of nickel, iron, and cadmium appear to be formed almost simultaneously in different degrees of hydration; but for a very rough approximation the following equations may be considered—

For the Nickel Iron Cell

$$Ni_2O_3 . 6H_2O + Fe . xH_2O = 2NiO . 9H_2O + Fe(OH)_2 . (x-4)H_2O$$

or

$$2Ni(OH)_3 + Fe = 2Ni(OH)_2 + Fe(OH)_2$$

and for the Nickel Cadmium Cell a combination of the above and

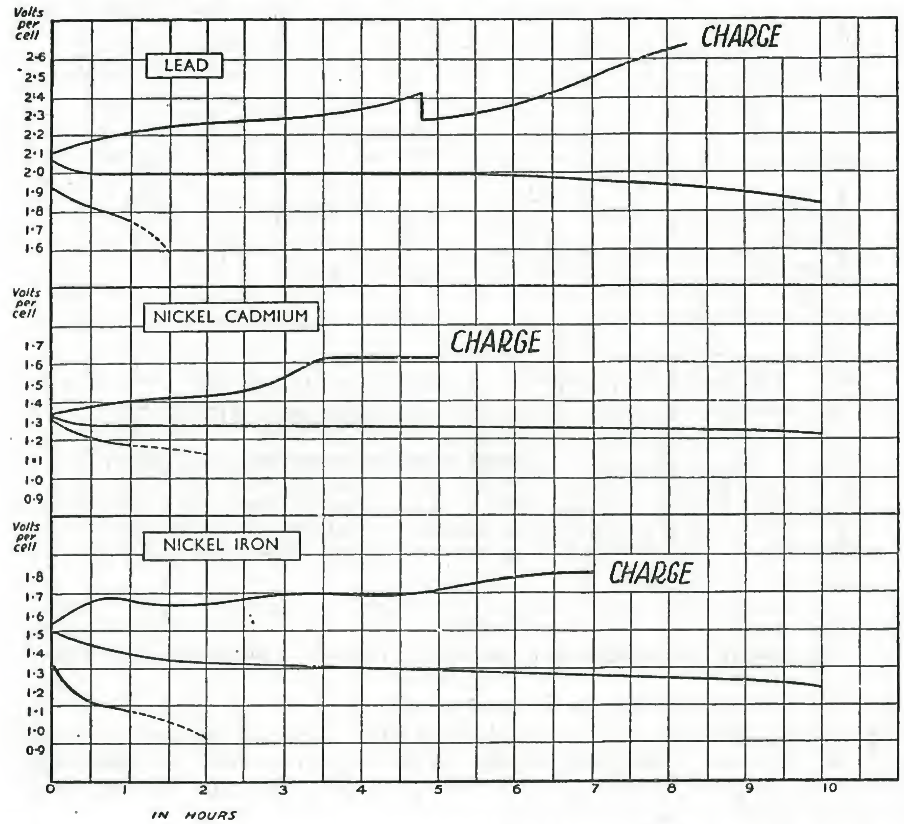
$$Ni_2O_3 . 6H_2O + Cd . yH_2O = 2NiO . 9H_2O + Cd(OH)_2 . (y-4)H_2O$$

or

$$2Ni(OH)_3 + Cd = 2Ni(OH)_2 + Cd(OH)_2$$

The electrolyte appears to take no active part in the reactions of the cell, and to function merely as a conductor. Apart from considerations of temperature rise and alteration in gravity due to electrolysis on charge, the quantity of electrolyte can thus be reduced to a minimum and the plates placed very closely together.

It will also be seen that although oxygen plays a part in the reaction, being transferred from one plate to another, no free oxygen is liberated on discharge, and therefore as no gases are evolved it would appear that a cell could be made absolutely unspillable by fitting solid stoppers. The iron present in a fully charged nickel iron cell, however, is not completely stable and tends to become oxidized slowly when standing idle; this is accompanied by the evolution of hydrogen and by a self-discharge of the cell. The cadmium negative, on the other hand, is completely stable and has in addition a stabilizing effect on the small quantity of iron, with the



VOLTAGE CHARACTERISTICS OF LEAD. NICKEL CADMIUM AND NICKEL-IRON CELLS

Fig. 22

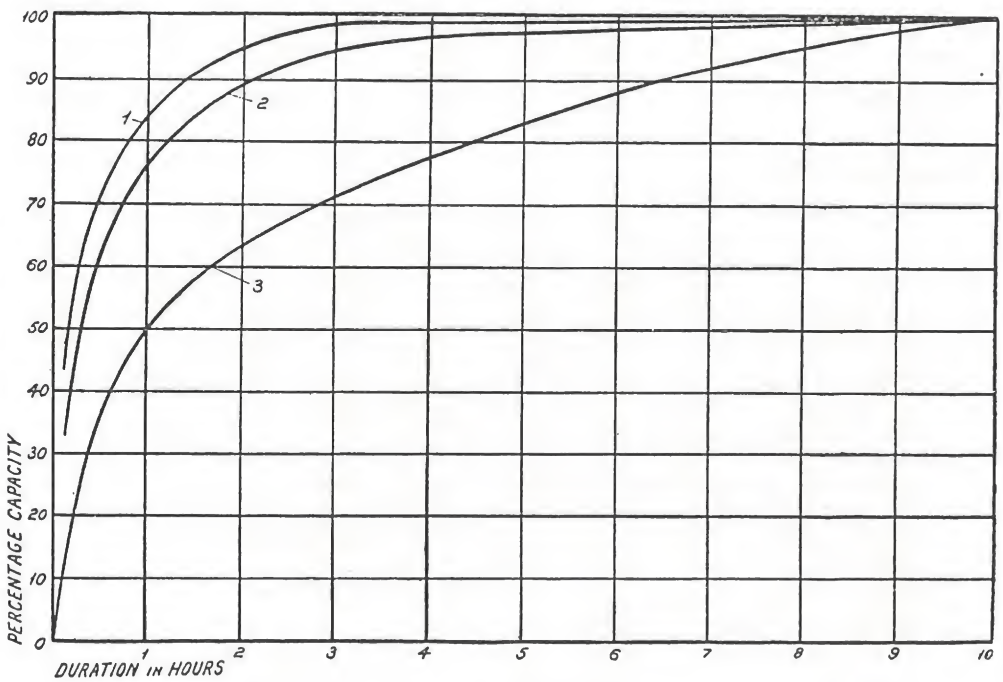
result that in the nickel cadmium cell there is no gassing, either on discharge or when standing idle, and no self-discharge. A nickel cadmium cell can therefore be made completely unspillable by fitting solid stoppers and thousands of batteries so fitted are giving excellent results in service. A very short period, however, should elapse after the completion of charge before inserting the solid stoppers in order to allow the gases generated during charge to escape completely.

The charging voltage of a pure nickel cadmium cell is from 1·35 to 1·50 volts, compared with 1·55 to 1·80 for a nickel iron cell, and the open circuit voltage of both types is between 1·25 and 1·40 volts, depending on the state of charge. Let us consider what this means. The voltage necessary to decompose the water content of a potassium hydroxide solution is of the order of 1·40 volts, which is appreciably below the charging voltage necessary to charge a nickel iron cell. A high degree of polarization is required to reduce the iron oxide, and the evolution of oxygen and hydrogen occurs during the whole of the charge, making the efficiency well below the theoretical figure. With the nickel cadmium cell, however, the evolution of gas is much less and the efficiency correspondingly higher, particularly as the cadmium oxide can be reduced with a low degree of polarization.

From this it is obvious that a nickel iron cell cannot be charged at very low rates and, on account of the large variation between charge and

discharge voltage, cannot be "floated." The characteristics of the nickel cadmium cell, however, are such that it can be trickle charged or "floated" in a similar way to the lead cell.

Although the actual resistance of the active materials in alkaline cells has been brought within satisfactory limits by the various means outlined earlier, the internal resistance of the normal alkaline cell of both types is appreciably higher than that of a lead cell. The nickel cadmium cell is by



1. Nickel Cadmium. 2. Nickel Iron 3. Lead.

Fig. 23

far the better of the two types and has an internal resistance which is only about half that of the nickel iron cell.

Fig. 23 shows the percentages of rated capacity obtainable at various discharge rates. If a battery is required for heavy discharge only, the capacity is frequently determined by considerations of terminal voltage only, and in this case it is almost always possible to install a nickel cadmium battery of much smaller rated capacity than would be necessary with lead. Switch closing and Diesel engine starting are examples of this class of duty.

All types of cells, lead, nickel iron, and nickel cadmium are affected in a similar manner by temperature. Normal temperature is usually taken as 15° C., and the capacity and voltage of cells on discharge increase as they are operated above normal. Beyond 45° C. the active materials may become adversely affected, and all battery manufacturers give a limit of about this figure above which cells should not be worked.

At temperatures below normal there is a very rapid falling off in both capacity and voltage, the lead cell being almost equally as bad as the nickel iron, while the nickel cadmium cell shows up comparatively well. Freezing of the electrolyte has no permanent effect on either the nickel iron or the

nickel cadmium cell, and only results in an inertness which is removed when the temperature is raised again, but in a lead cell it is often disastrous to the plates.

PERCENTAGE CAPACITY AVAILABLE AT NORMAL RATE

	15° C.	5° C.	– 5° C.	– 15° C.
Lead	100	84	65	43
Nickel cadmium	100	96·5	92	74·5
Nickel iron	100	79	52·5	15·8

Generators—Motors

The movement of a metallic conductor through—not along—the lines of force in a magnetic field creates a difference of electrical pressure between the ends of the wire, and if the two ends are joined together by means of a suitable conductor, so long as relative motion is maintained between the conductor and the magnetic field, a current of electricity due to this difference of electrical pressure will flow through the system. It is important to note that it is a difference of electrical pressure, and not a current, that is created. Such a machine requires the application of mechanical force to obtain the relative motion of conductors and magnetic field, producing in return the difference of electrical pressure which may be used to cause a current of electricity to flow, and is called a generator. A machine designed to operate in the reverse sense, viz. to produce mechanical force by the application of a difference of electrical potential to the conductor, is called a motor. In many cases the same machine can be made to operate either as a motor or as a generator, but this is not an invariable rule, due to peculiarities of design.

The magnetic field of either a generator or a motor may be produced by the use of either permanent magnets or electro-magnets. Permanent magnets are used in some classes of small machine, such as magnetos and the generators used in connection with certain makes of electrical revolution counters. The use of permanent magnets, of course, involves the use of hardened alloy steel in the construction, but with electro-magnets it is permissible to use soft or malleable iron or mild steel. The current used to energize the coils of the electro-magnets is usually obtained from the machine itself, if of the direct current type, but in certain cases it is obtained either from another and smaller generator, which is often incorporated in the main generator, or from storage cells.

Alternators, or generators designed to produce alternating current, are a class of machine which requires such separate outside excitation, since they require a source of direct current for field excitation purposes. A self-exciting generator operates by reason of the fact that even soft iron will retain a certain small amount of residual magnetism, sufficient to enable the armature coils to produce a small E.M.F. This small E.M.F. will cause a small current to flow in the field coils, which will in turn increase the magnetic flux, thus increasing the E.M.F. in the armature, which again increases the field excitation, and thus a building-up process goes on until the magnetic circuit reaches saturation point. A new generator may require the application of a magnetizing current from an outside source on its first run up, but thereafter there will normally be sufficient residual magnetism to enable it to be self-exciting.

After allowing a small amount of energy to compensate for friction losses and heat losses, the amount of mechanical energy required to drive a generator is directly proportional to the amount of electrical energy—watts—which the machine is giving out. Where the source of mechanical energy is an engine fitted with a governor, it will be easy to watch the action of the governor respond to the varying output of the generator. In the case of an electric motor, on account of certain electrical reactions within the machine, the nature of which it is unnecessary to consider here, the motor will only take that amount of electrical power from the supply mains which is proportional to the actual

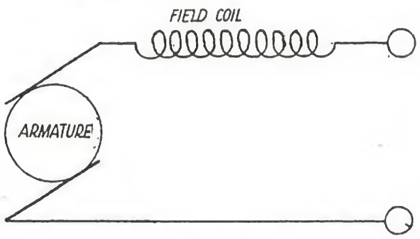


FIG. 24

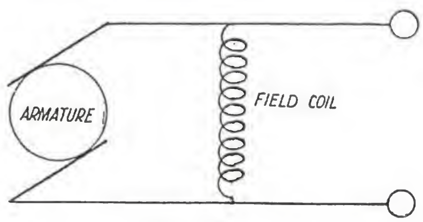


FIG. 25

load on the machine, apart from small inherent losses due to inefficiency of conversion.

In direct current generators, the portion in which the electrical difference of pressure is produced, and whether it be stationary or rotary, is termed the **armature.** The other portion is usually designated the **field magnets.** Direct current dynamos are divided into four main classes, viz.—

Separately excited dynamos.
Series-wound dynamos.
Shunt-wound dynamos.
Compound-wound dynamos.

Reference has already been made to the first class. On aircraft, it is only met with in the case of certain high voltage generators used for wireless purposes. In such machines the high voltage main armature current would be unsuitable for field excitation, therefore, a small secondary armature, mounted on the same shaft as the main armature, is caused to rotate in a secondary magnetic field system attached to the main field framework. The low tension current from the small secondary armature is used to excite the main field system. In some cases this secondary armature is designed on a sufficiently generous scale to enable it to supply low tension current for battery charging, and general purposes on the aircraft, apart from wireless.

In **series-wound** dynamos the field coils are wound with a comparatively few turns of thick wire, through which the whole of the current given off by the armature flows. The arrangement is illustrated diagrammatically in Fig. 24. The value of the resultant E.M.F. depends on the strength of the magnetic field, the speed of rotation, and the number of wires joined in series on the armature. Dynamos of this type are only satisfactory under conditions of constant speed and constant load, and are therefore quite unsuitable for use on aircraft. In a series-wound motor, the E.M.F. of the supply being constant, the speed will decrease as the load increases, and, conversely, the speed will increase as the load decreases. The starting torque of a series-wound motor is high, but, in general, it is unsuitable for aircraft use.

In the third class of dynamo, the **shunt-wound** type, in place of passing the whole current from the armature through a few turns of thick wire, only a small proportion of the total armature output is used to excite the field coils, which, in this case, consist of a greater number of turns of finer gauge wire, having a high resistance. For a given size of field magnet it is necessary to have a given number of ampere-turns to obtain the desired maximum magnetic flux. Whereas in the series-wound machine this is attained by few turns and many amperes, in the shunt-wound type it is attained by many turns and few amperes. Hence the thick wire in the former case and the fine wire in the latter. The arrangement of a shunt-wound machine is shown diagrammatically in Fig. 25. The E.M.F. will now be almost independent of the load, provided the speed be kept constant, because the resistance of this part of the circuit will remain constant, and, in accordance with Ohm's law, the same amount of current will flow through the shunt coils at all times. Hence the magnetic field will remain steady, and so, theoretically, will the resultant E.M.F. of the dynamo as a generator, or, if the dynamo be run as a motor, the speed will remain practically constant at all loads. As a matter of fact the E.M.F. of a shunt-wound dynamo tends to drop slightly as the load is increased, owing to the effect of armature reaction, and this is compensated for by means of a small adjustable external resistance, or by other means which will be referred to later.

The fourth class of dynamo (**compound-wound**) is really a combination of the characteristics of the series-wound and shunt-wound machines. The field magnets are provided with two separate windings. One winding consists of a few turns of heavy gauge wire, and carries the whole output of the armature. The other winding consists of many turns of finer gauge wire, and is connected straight across the armature, but on account of its high resistance it absorbs only a small proportion of the total output of the armature. The arrangement is illustrated diagrammatically in Fig. 26.

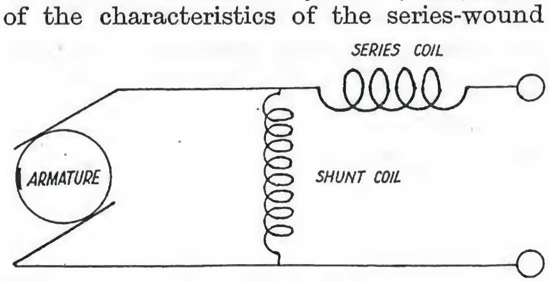


FIG. 26

COMMUTATION

It has already been stated that the basic principle of the dynamo is the cutting of magnetic lines of force by a moving conductor. In its simplest form, such a conductor would take the form of a plane rectangular loop of wire, having its ends connected to two insulated metallic rings mounted on the armature shaft. By arranging fixed "brushes" to rub on these rings it is possible to make contact with the ends of the wire whilst the loop is rotating at high speed. But as each ring is connected to one arm of the loop, which is cutting alternately the magnetic lines of force first at a north pole and then at a south pole, each ring in turn becomes the negative and then the positive pole of the armature circuit, and the E.M.F. produced is an alternating one. This alternating E.M.F. may be "commuted" to a direct E.M.F. by the use of a device called a commutator.

The commutator consists of a series of insulated metal bars, segmental in section, mounted in a framework fixed to the armature shaft, all the

metal bars being parallel to the axis of the shaft, and arranged concentrically round it. In a bipolar machine, the ends of the armature loops are connected to diametrically opposite bars of the commutator, and a pair of diametrically opposite fixed brushes are arranged to rub on the surfaces of the bars as they rotate with the armature shaft. Thus, when one arm of a loop is sweeping past a north magnetic pole its end is connected to a commutator bar passing under one of the fixed brushes, and the polarity of that brush will be positive, and the other brush must therefore be negative. By the time the arm of the loop has completed half a revolution it is sweeping past a south magnetic pole, but the commutator bar to which it is connected has also completed half a revolution and is now under the second brush. Thus, although the E.M.F. in the arm of the loop has reversed, the commutator bar to which it is connected is now passing under the other brush, and hence the polarity at the brushes is maintained constant. This is the basic principle of commutation, but in practice it is elaborated by increasing the number of loops of wire on the armature, and by increasing the number of poles in the magnetic system.

Considering the case of a single commutator bar, we see that its E.M.F. will rise from zero to a maximum in one direction, then die away to zero and rise to a maximum in the opposite direction, and die again to zero, all in the course of a single revolution.

The coils of wire which carry the field exciting current are highly inductive, and so, to a lesser extent, are those on the armature. Since the current flowing in these coils passes through the commutator bars and brushes, the circuit is necessarily broken twice in each revolution of the armature. The precautions which have to be taken when breaking a highly inductive circuit have already been referred to, and in the case of the dynamo the avoidance of heavy inductive sparking at the commutator brushes is effected by so placing the brushes in relation to the commutator that at the moment a commutator bar is passing from under the brush the E.M.F. of the armature winding is passing through zero potential. It will be appreciated, however, that the effects of self-induction prohibit this change from being effected instantaneously, although the reversal of current has practically to be done during the very limited time each coil is short-circuited under the brush. How short this period is, is evident when it is considered that a dynamo making 4,800 r.p.m., or 80 rev. per sec., and fitted with a commutator containing only 20 sections, has any set of coils under the action of a bush for the 1/1600 part of a second only. This time is too limited to permit of the reversal of current, and were the brushes set precisely at the neutral position, sparking would inevitably occur. To overcome this difficulty the brushes are set a little forward from the neutral position in the case of a generator, and a little behind the neutral position in the case of a motor. The result of this adjustment of the brushes is that during the time the coil is short-circuited it is acted upon by the magnetic field into which it is about to be thrown, and, therefore, there is a reverse E.M.F. generated in the coil while still under the action of the brush. The angle through which the brushes are set forward is termed the **angle of lead**, and similarly the angle through which the brushes are set back—in the case of a motor—is termed the **angle of lag**. These settings vary with the load on the machine.

The output of a generator is controlled largely by the permissible temperature rise of the windings. The passage of a current of electricity along a wire has a heating effect on the wire, which increases as the current density in the wire is increased. This heating effect will obviously be

most marked in the case of well protected windings, and least marked in the case of open and well ventilated windings. For this reason aircraft generators are usually installed in such a position that they receive the full cooling effects of the slipstream of the airscrew. By this means the output may be increased by about 100 per cent over what the same machine could safely give if deprived of the cooling advantages of an air blast.

When considering the output marked by the makers on an aircraft dynamo, therefore, it is necessary also to consider where it will be installed in the aircraft, and to regulate the permissible load to be taken from it accordingly.

A 12-volt system for lighting and general low tension supplies on aircraft is practically universal, and this voltage has been fixed as offering the

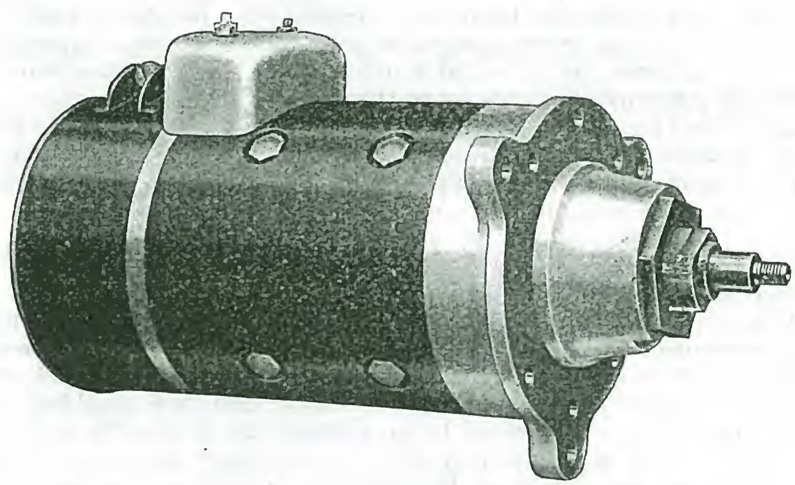


FIG. 27. ENGINE-DRIVEN TYPE A.T. 149

24 volts. 350 watts at approx. 3,600 r.p.m. Overall length $12\frac{7}{16}$ in. Diameter 5 in. Weight $28\frac{1}{2}$ lb.

Also designed to give its output over a wide range of speeds, this constant current machine is adapted for flange mounting. The switching is so arranged that this Dynamo gives full output only when the navigation lamps are in use. As shown, this machine is arranged for mounting vertically, but it can be supplied for horizontal drive either by engine or by means of an airscrew.

(By courtesy of Rotax Ltd.)

best compromise and economy of weight. A lower voltage would involve the use of much heavier cables, terminal blocks, switchgear, etc., and would give practically no corresponding saving in weight of the generator itself. A higher voltage would show some saving in weight of cables, but the problem of weight of a suitable accumulator then arises.

The particular types of generator in general use may be classified as follows—

1. Approximately 200 watt, plain shunt-wound machines, requiring an external regulator to maintain constant voltage under all conditions of speed and load.

2. Approximately 200 watt shunt-wound machines, fitted with a third brush and additional field winding for voltage regulation over a fairly wide range of speed and load.

3. Approximately 500 watt plain shunt-wound machines, similar to (1) above.

4. Dual purpose high and low tension generators of the Marconi-Newton type.

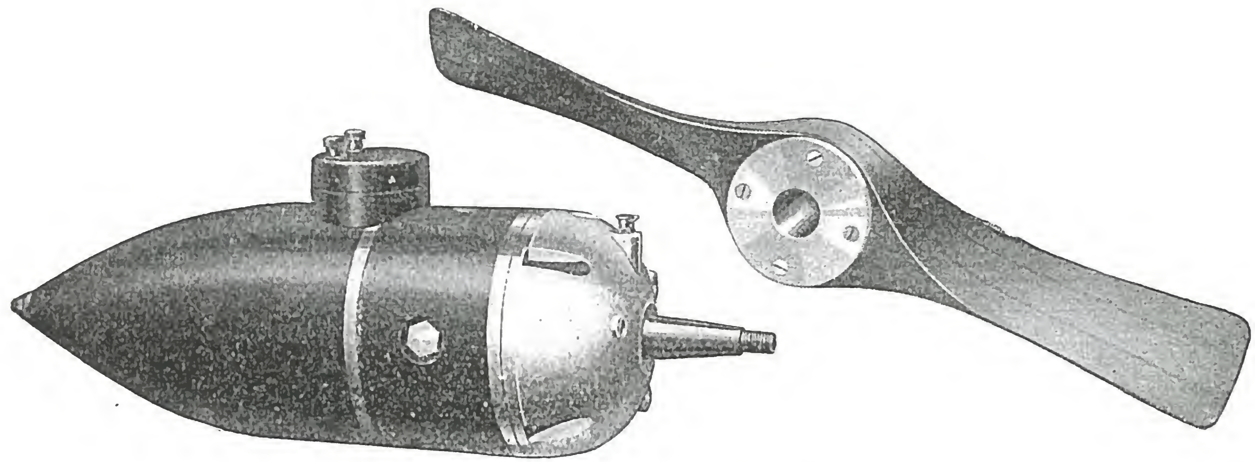


FIG. 28. WIND-DRIVEN TYPE A.T. 153

12 volts. 150 watts at approx. 3,500/4,000 r.p.m. Overall length $12\frac{1}{4}$ in. Diameter $4\frac{1}{8}$ in. Weight $11\frac{3}{4}$ lb.

(By courtesy of Rotax Ltd.)

The methods of driving aircraft generators include (*a*) windmill drive, with wooden or metal windmills having fixed blades. The windmill chosen for use with any particular generator will depend on the generator speed and output, the position of the generator on the aircraft, i.e. in or out of the slipstream, and the normal speed of the aircraft; (*b*) direct drive from the main aircraft engine, either by fixed gearing or by flexible shaft; (*c*) by windmills of the automatically variable pitch type, such as are usually fitted on the Marconi-Newton dual purpose generators.

Windmills for use with electrical generators which are constructed to the designs shown on the table appended hereto are approved for use on civil aircraft.

Type	Drg. No.	Range of Total Airspeeds over Windmills*	Corresponding Range of r.p.m.	Generator for which Approved
Fixed pitch wooden windmills—				
Vickers . .	A.305	80–110 m.p.h.	4,500–6,300	Vickers D.P.A. 150 watt generator
	A.342	110–140 ,,	4,700–6,150	
Rotax . . .	H.9	90–162 ,,	3,500–7,500	Rotax generators Types AT. 153 and AT. 157
	H.10	93–171 ,,	3,500–7,500	
	H.11	110–198 ,,	3,500–7,500	
	H.17	75–110 ,,	3,500–5,500	120 watt DP. generator (A.M. Type)

* Including slipstream if any.

In the case of (*a*) and (*b*) above, it will be obvious that the speed of the generator will vary considerably under different conditions met with in ordinary flight, and therefore some means of regulating the generator voltage becomes essential. There are types of automatic voltage regulators, installed remote from the generator, which will be described later. There is also the type of generator provided with compensator windings designed to regulate the current over a wide speed range. The automatically variable pitch windmill is a very successful fitment for obtaining a steady voltage, because of its governing action, which maintains the speed of the generator practically constant over wide ranges of load and air speed.

On the whole, aircraft generators are very reliable machines, and their maintenance requirements are not great. The armatures are normally mounted in ball bearings, which call for occasional lubrication only, and for this purpose anti-freezing grease is usually specified by the makers. The brush position is usually fixed, and no adjustments of this are possible. The brushes will wear with use, and should be inspected regularly, and renewed as necessary. The commutator may become dirty and worn with use. Only fine grade carborundum cloth should be used for cleaning purposes. If deep burning or pitting has occurred, or the commutator has worn oval, or if flat spots have developed, the whole armature should be removed from the generator, mounted in a lathe, and the surface of the commutator cleaned up with a very sharp narrow-nosed tool, and the insulation between the bars then slightly recessed. The interior of the generator should be kept clean, and especially should it be kept free of moisture and carbon dust, which will otherwise accumulate from worn

brushes. Should a definite fault, not attributable to ordinary lack of maintenance, develop in a generator, the following notes may be of assistance.

1. *Brush vibration*, may be due to rough commutator surface, commutator worn oval, loose commutator bars, or projecting insulation material between the commutator bars.

In each of these cases the remedy will be obvious. It should be remembered that the insulating material between the bars of the commutator should be recessed slightly below the surface of the bars.

2. *Sparking at brushes*, may be due to unsuitable material of the brushes, badly "bedded" brushes, unsuitable spring pressure behind the brushes, brushes may be covered with dust, or grease, or oil, etc., a loose

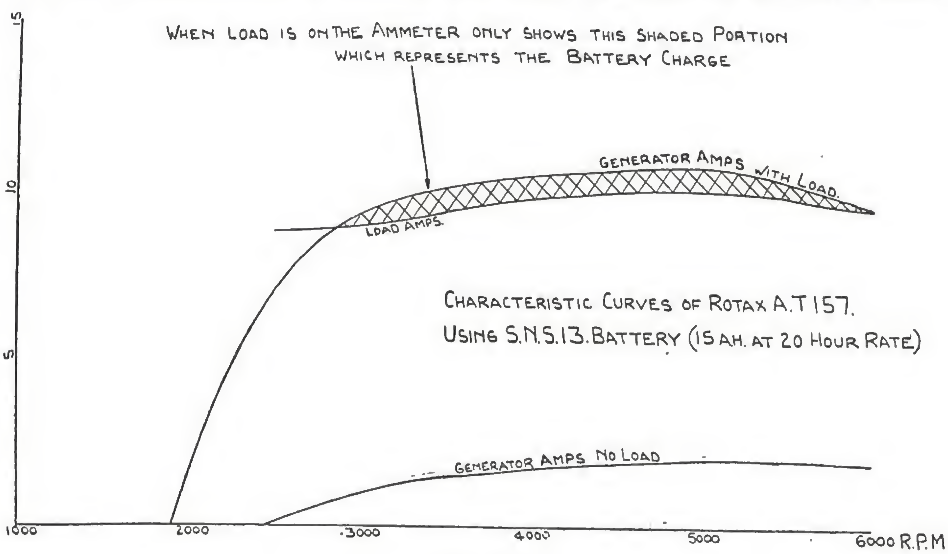


FIG. 29

connection between a commutator bar and the armature winding, a break in the armature winding, or too high a generator speed.

3. *Commutator burnt* or covered with a black coating. This fault is often due to the brushes being of too soft material, which is decomposed, and covers the commutator with a film which increases the contact resistance, thus heating the brushes and commutator. The treatment of the commutator and carbon brushes, and the quality of the latter, will have a great influence on the sparkless running of a continuous current machine. The different sorts of carbon brushes show great differences in quality, hardness, and conductivity, so that a machine will work best with a particular sort of brush. Generally speaking, machines for high voltages will work best with hard carbons, while for low voltage machines soft carbons are more suitable.

4. *Failure to generate* is often due to loss of residual magnetism, which may be caused by violent vibration, or a reversal of the magnetism which has been insufficient to build up a residual field in the opposite direction. To build up the magnetism again, send a current from an external source through the field coils. A reversal of field connections, or change in direction of rotation, will produce similar symptoms of a failure to generate, as also will poor contact between brushes and commutator, or too low a speed of rotation.

Whilst the foregoing may be regarded as a résumé of the usual type of faults found in machines of standard design, it will be appreciated that proprietary makes of dynamo and allied electrical equipment may be liable to disorders peculiar to each, and due to the special feature of design introduced by the makers. The following notes on location and remedy of troubles are therefore reproduced in full by courtesy of Rotax Ltd., from their Instruction Booklet No. 229.

CONSTANT CURRENT TYPE DYNAMOS

Symptoms	Probable Fault	Remedy
Ammeter fails to indicate charge when running with no lights in use, or gives heavy discharge with lights on.	Dynamo not charging, due to: broken or loose connection in charging circuit causing field fuse to blow.	Examine charging circuit wiring. Tighten loose connection or replace broken lead. Particularly examine battery connections. Fit replacement fuse.
	Commutator greasy or dirty.	Clean with soft rag moistened in petrol.
	Reversed polarity due either to dynamo having been motored with field switch (charge) "off" or the battery being accidentally connected the wrong way round.	Move charge switch and lighting switch to "on" position, and run dynamo normally. If trouble is not cured, short field fuse with a length of wire, and with lighting switch and charge switch still "on," motor the armature by shorting terminals 5 and A on the cut-out. The dynamo should then function correctly. Remove short circuiting wires and replace fuse.
Ammeter gives low or intermittent charge reading.	Dynamo giving low or intermittent output, due to—	
	Loose or broken connections in dynamo circuit.	Examine charging circuit wiring. Tighten loose connections or replace broken lead. Particularly examine battery connections.
	Commutator or brushes greasy.	Clean.
	Brushes worn, not fitted correctly, or wrong type.	Replace worn brushes. See that brushes "bed" correctly.

CONSTANT CURRENT TYPE DYNAMOS—(*contd.*)

Symptoms	Probable Fault	Remedy
Ammeter gives high charge reading.	Dynamo giving high output due to—	
	Loose connections in dynamo charging circuit.	Examine charging circuit wiring. Particularly battery connections. Tighten loose connections.
	Battery acid level low.	"Top up" cells with distilled water.
	Brushes not fitted correctly.	See that brushes "bed" correctly.
	Control brush position altered.	Have control brush adjustment re-set.
Lamps give insufficient illumination.	Battery discharged.	Charge battery either by a long period of daytime running or from independent electrical supply.
	Bulbs discoloured through use.	Fit new bulbs.
Lamps light when switched on, but gradually fade out.	Battery discharged.	As above.
Brilliance varies with speed of plane.	Battery discharged.	As above.
	Battery connection loose or broken.	Tighten connections or replace faulty cables.
Lights flicker.	Loose connection.	Locate loose connection and tighten.
Failure of lights.	Fuse blown.	Examine wiring for faulty cables and remedy. Fit replacement fuse.
	Battery discharged.	As above.
	Loose or broken connections.	Locate and tighten loose connections or remake broken connection.

CONSTANT VOLTAGE TYPE DYNAMOS

Symptoms	Probable Fault	Remedy
Ammeter fails to indicate charge when running with no lights in use, or gives heavy discharge with lights on.	Dynamo not charging due to: broken or loose connection in charging circuit or regulator out of adjustment, causing field fuse to blow.	Examine charging circuit wiring. Tighten loose connection or replace broken lead. Particularly examine battery connections. Fit replacement fuse. Return regulator to Service Depot for adjustment.
	Commutator greasy or dirty.	Clean with soft rag moistened in petrol.
Ammeter gives intermittent charge reading.	Dynamo giving low or intermittent output, due to—	
	Loose or broken connections in dynamo circuit.	Examine charging circuit wiring. Tighten loose connections or replace broken lead. Particularly examine battery connections.
	Commutator or brushes greasy.	Clean.
	Brushes worn, not fitted correctly, or wrong type.	Replace worn brushes. See that brushes "bed" correctly.
Ammeter gives excessive charge reading.	Dynamo giving high output due to—	
	Regulator out of adjustment.	Return regulator to Service Depot for adjustment.
Lamps give insufficient illumination.	Bulbs discoloured through use.	Fit new bulbs.
Brilliance varies with speed of plane.	Battery connection loose or broken.	Tighten connections, or replace faulty cables.
Lights flicker.	Loose connection.	Locate loose connection and tighten.
Failure of lights.	Fuse blown.	Examine wiring for faulty cables and remedy. Fit replacement fuse.
	Loose or broken connection.	Locate and tighten loose connection, or remake broken connection.

Location and Remedy of Troubles

Although every precaution is taken to eliminate all possible causes of trouble, failure may occasionally develop through lack of attention to the equipment, or damage to the wiring. The most probable faults are tabulated, according to the symptoms which are displayed, in the foregoing fault-finding tables.

A few hints on the best way to make use of these tables are given, as the sources of many troubles are by no means obvious. In some cases, a considerable amount of deduction from the symptoms is needed before the cause of the trouble is disclosed.

Much evidence can be gained from the ammeter. If, for instance, no charge reading is indicated when the engine is running with the charging switch in full charge position and the load "off," the dynamo is failing to charge. To ensure that the ammeter is not at fault, the lights should be switched on, while the plane is stationary, when a reading on the discharge side of the scale should be observed. Again, if the maximum ammeter reading is much below normal when the dynamo is charging, or if the needle fluctuates when the engine is running steadily, a low or intermittent dynamo output can be suspected. The dynamo may have been neglected, and the trouble could be caused by, say, worn brushes or a dirty commutator.

Should the intensity of the lights vary, or should they fail entirely, it is probably due to the battery terminals being allowed to corrode and the consequent breaking of a connection. If the cause of the trouble is not located at the battery, the switchboard should next be examined; particularly, see that all the terminals are quite tight. If one particular lamp does not light, look for a broken filament or a loose connection at the lamp. When the plane is stationary and the lamps light when switched on, but gradually go out, the battery is probably exhausted.

Wiring*

All cables and wires used for electrical purposes on aircraft must be manufactured in accordance with an approved specification, and must be installed in accordance with an approved installation drawing or diagram. Cables manufactured in accordance with B.S. Specification E.3. or D.T.D. Specification E. & I. 351 and others are already approved. Only cables consisting of multi-stranded conductors of high conductivity tinned copper wires, with an adequate covering of high-grade insulating material, and a satisfactory external protection against mechanical damage, are likely to obtain official approval. It must be remembered that electrical wiring in aircraft is subject to the very insidious and destructive effects of vibration and extremes of weather and temperature, and for these and other reasons it is essential that the very greatest care be taken with their installation. The principal points to be observed are—

1. No joints in cables are permitted, except by means of approved type terminal blocks.
2. All cable ends must be properly prepared and finished off.
3. Where cable ends are soldered, only flux consisting of resin, or resin dissolved in methylated spirit, may be used. This is to avoid the gradual corrosive effects produced by most other fluxes. Such corrosive effects are very insidious and are often only detected by the gradual breaking off of the strands of wire near to the soldered end, thus resulting in decreased conductivity and heating up of the remaining strands.
4. Every strand of the conductor must be brought into circuit. Under

* Based upon Inspection Leaflet 19 of *A.P.* 1208 and reproduced by kind permission of the Controller, His Majesty's Stationery Office.

no circumstances may the conductivity of a conductor be reduced by cutting off a certain number of strands in order to accommodate the remainder in a terminal which is really too small for its proper duty. Every care must be taken to protect cables where they pass over sharp edges of wood or metal, or through holes which are not properly flared or bushed. Short lengths of systoflex, or similar protective tubing, may be used.

5. Cables should be cleated at frequent intervals, say 8 in. to 12 in., depending on circumstances. A short piece of systoflex or similar tubing should be slipped over the cables under each cleat.

6. Cables should be cleated sufficiently close to the ends to prevent any mechanical pull coming on to the conductors at the connections in the terminals.

7. Particular care should be taken with cables passing through open cockpits to protect them from accidental damage due to movements of passengers or crew, from petrol, dope, and oil, and from the effects of rain or weather.

8. It is always a good plan to run cables in light metal ducts, which support them throughout their length, but care must be taken to avoid all sharp edges in the ducts, and to provide them with adequate ventilation to avoid any possibility of moisture condensing within them. If necessary, drainage holes should be provided.

9. General service circuits (lighting, heating, etc.), should be installed in the aircraft as remote as possible from the wiring of W/T circuits, in order that the danger of interference with W/T communications may be reduced to a minimum.

10. Items of electrical equipment containing permanent or electro magnets, or strongly magnetic solenoids, must be installed at a sufficient distance from the navigating compass to avoid the introduction of errors into the readings of the latter. For a similar reason, electric cables must be "paired," i.e. positives and negatives run together in such a way that the inductive effects of one are neutralized by the inductive effect of the other, or, if run singly, they must be kept well away from the compass.

After completing the wiring on the aircraft, due care having been given to the foregoing points, and all connections to lamps, instruments, etc., being completed, it is necessary to apply tests to the installation to verify connections and standard of workmanship. The necessary tests are three in number, viz. (*a*) insulation tests; (*b*) continuity test; and (*c*) operational test.

Insulation Tests

These should be carried out with a 500-volt megger, and the results obtained in each case, after a continuous application of the test pressure for at least one minute, should not be less than the value obtained from the formula

$$\frac{\text{20 megohms}}{\text{No. of points in circuit}}$$

subject to a minimum value of the insulation resistance obtained by this formula of 2 megohms. Circuits under test should be closed at the switches, but have lamp bulbs, and similar detachable items, removed. The insulation tests are taken in two stages, viz. (i) a test for insulation resistance "between poles" of all circuits. The test involves the connection of the two megger terminals to the two sides respectively of each circuit or sub-circuit in turn. A number of circuits or sub-circuits may be bunched together if convenient, the object of the test being to verify that the

insulation between positive and negative poles of all circuits is satisfactory. Should a low reading be obtained when testing a "bunch" of circuits simultaneously it will be necessary, of course, to separate the circuits and test each individually in turn to locate the defective one, and then to trace and rectify the fault. (ii) A test for insulation resistance to "earth." For the purpose of this test one terminal of the megger is connected to "earth," i.e. the metallic structure of the aircraft, the other terminal being connected in turn to one end of each separate length of insulated conductor in the installation. A multi-core cable must be tested at one end of each core. In this case, the object of the test is to verify that every conductor is sound and has not been damaged in such a way as to permit connection between that conductor and the structure of the aircraft.

It may be as well to mention here that it is a definite Air Ministry requirement that all electrical circuits on aircraft must be of the double pole insulated type, i.e. "earth return" circuits are not permitted. The single exception to this rule concerns the low tension magneto control circuit, where, under certain circumstances, an "earth return" is permitted.

Continuity Test

All wiring is to be tested from point to point, using a battery and either a bell or a lamp as indicator, the smaller sizes of wires being subjected to a slight tension whilst undergoing this test. The bell or lamp used for this test should carry a reasonably heavy current, so that, in the event of a poor or intermittent contact occurring anywhere in the circuit, the relatively heavy current required by the bell or lamp will have difficulty in passing, and the chances of detecting the fault thereby increased. A current of 2 to 3 amperes is desirable.

Operational Test

An accumulator of the appropriate voltage is to be temporarily connected to the relevant accumulator leads, and all switches, etc., operated several times to ensure that each circuit of the system is working satisfactorily and is unaffected by the working of any other circuit. On completion of inspection and testing, all necessary records should be made and certified in the aircraft inspection record.

The following table shows the usual types of circuits in use on aircraft, and some of the appropriate approved specifications of wires which may be used in connection therewith.

Low Tension Circuits

Unscreened. (1) For general service and wireless circuits in fuselages and wings where special protection against weather, petrol, oil, mechanical damage, etc., is not required.

Spec. B.S. E.3. Section I. (Glazed cotton braided flexible cords and cables.)

Spec. R.D. Inst.I.M. D.3667–4–50 G.B. (Cellulose varnished.)

(2) As for (1) but where a reasonable amount of additional protection is required.

Spec. R.D. Inst.I.M. D.3667–4–50 G.B. (Cellulose varnished.)

Spec. B.S. E.3. Section II. (Flexible cords and cables with waterproof covering.)

(3) As for (1) but where maximum protection is required, e.g. cables exposed outside fuselage to slipstream, also low tension ignition leads.

Spec. B.S. E.3. Section IV. (Flexible cords and cables with cab tyre sheathing.)

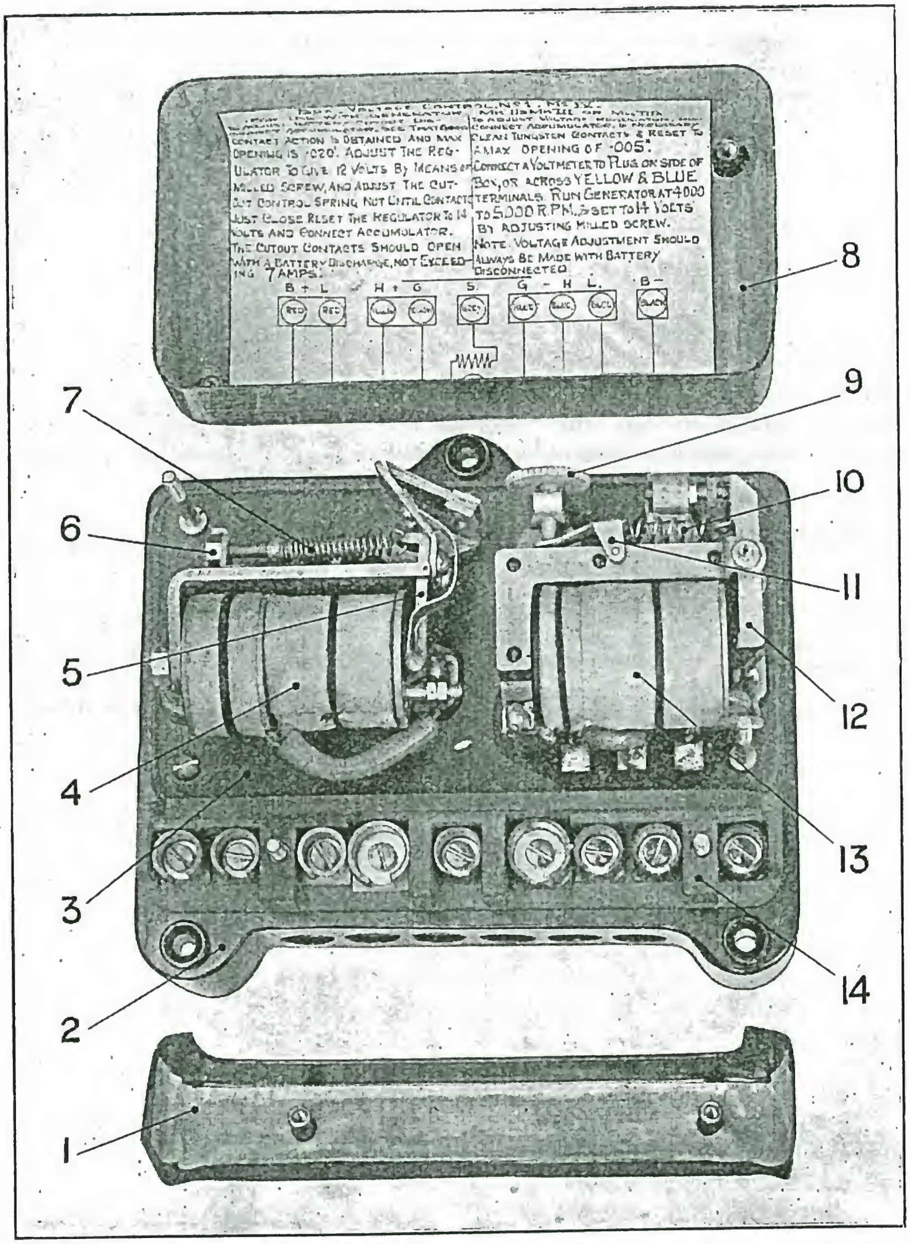


FIG. 30. R.A.F. NO. 1, MARK IV, VOLTAGE REGULATOR AND BATTERY CUT-OUT

(From A.P. 1095, by courtesy of the Controller of His Majesty's Stationery Office)

Screened. (1) For general service and wireless circuits in unexposed positions and requiring screening.

Spec. A.M. Specification E. & I. 351. (The "met" series, i.e. all cable names terminate in the suffix "met.")

Spec. A.M. Specification E. & I. 352. (With rubber sheathing over the metal braiding.)

(2) As for (1) but for use in more exposed positions, and for ignition circuits.

Spec. B.S. E.3. Section V. (Flexible cords and cables with cab tyre sheathing and metal braiding.)

HIGH TENSION CIRCUITS

Unscreened. Ignition leads to sparking plugs; aerial reel to transmitter receiver; starting magneto to main magneto.

Spec. B.S. E.I. Section I. (Plain rubber finish cable.)

Spec. A.M. Specification E. & I. 309. (Rubber and varnished cotton braided.)

Screened. Ignition leads to sparking plugs and starting magnetos to main magnetos.

Spec. B.S. E.1. Section II. (Metal braided cables.)

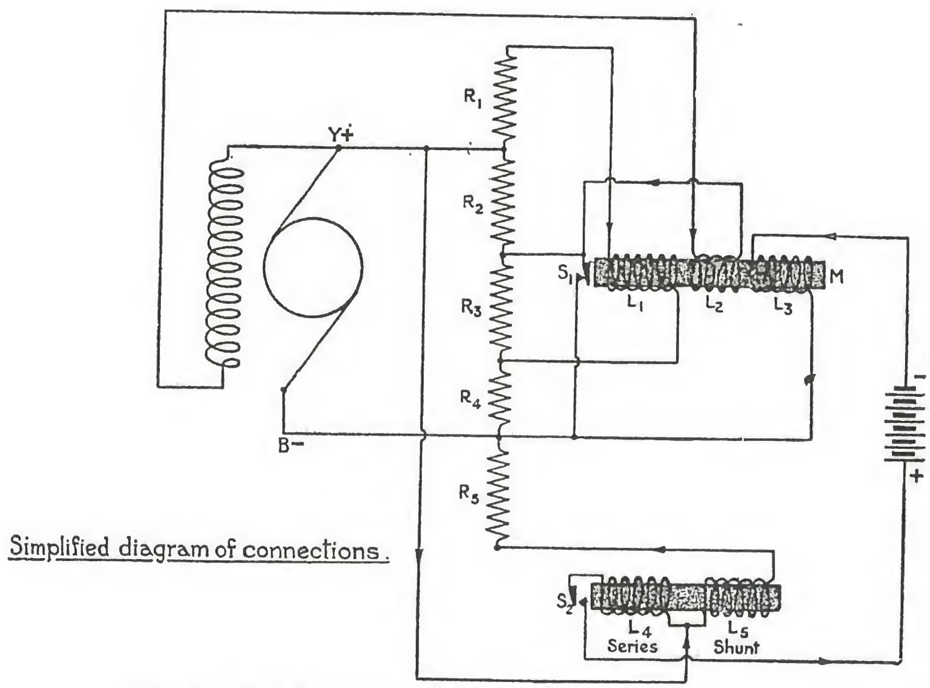


FIG. 31. R.A.F. No. 1, MARK IV, VOLTAGE REGULATOR
(From A.P. 1095, by courtesy of the Controller of His Majesty's Stationery Office)

Voltage Regulators

A plain shunt-wound dynamo which is driven at a varying speed obviously requires some means of maintaining its voltage at a constant value, or confined within very narrow limits, and on aircraft this object is usually achieved by means of an automatic voltage regulator operating on what is known as the Tirril principle. Such regulators are normally installed in a vertical position in the cockpit, or in some other position where they can be conveniently inspected and adjusted, since they contain a vibrating armature and contact points which require occasional cleaning and adjustment.

The R.A.F. Mark IV type regulator, which is available for use on civil aircraft, consists in its essentials of an electro-magnet, with a spring-loaded armature, and various resistances for smoothing and other purposes. It

also contains a battery cut-out, which will be dealt with separately. Referring to Fig. 31, the electro-magnet is indicated at M, and is energized by the two coils L_1 and L_2. L_1 is connected across the generator armature through the resistances R_1 and R_4, while L_2 carries the generator field current and acts in opposition to L_1. When the generator is started up, the contacts S_1 are closed. The resistances R_3 and R_4 are thus short-circuited, and the negative end of the generator field is connected to "B –" through the coil L_2, so that the generator builds up on full field except for the negligible voltate drop across L_2.

When the generator voltage reaches a certain predetermined value, the electro-magnet M attracts a small soft iron armature against the pull of a control spring, thus opening the contacts S_1. The resistances R_3 and R_4 are thereby inserted in the generator field circuit, thus reducing the generator field current and causing the generator voltage to fall. When the voltage has fallen by a certain amount, the contacts S_1 are closed by the control spring, which overcomes the weakening attraction of the soft iron armature by M. This causes the voltage to rise again, and the cycle of operations is repeated. An approximately constant mean voltage is thus maintained at any load and speed within the capacity of the generator.

By connecting the coil L_1 to the junction of the resistances R_3 and R_4, a "bucking" effect is obtained. When the contacts S_1 open, an immediate reduction of current in coil L_1 is produced, due to the combined effect of the resistances, the effect of this being to speed up the operation of the regulator. This improves the steadiness of operation, especially on load, and materially reduces the amplitude of the voltage ripple caused by the regulator. The resistance R_1 has a negligible temperature coefficient and acts as a series swamping resistance to the coil L_1. By this means the effects of temperature changes on the controlled voltage are very greatly reduced.

The "bucking" effect described above is dependent upon the periods of time during which the contacts are opened and closed, which in turn depend upon the mean field current required to meet the generator condition. As this field current depends upon speed and load conditions, the controlled voltage will vary from this cause. This variation is almost entirely eliminated by the addition of the compensating coil L_2, which carries the generator field current, and which is connected so that it opposes the main winding L_1. The coil L_3 is a low resistance winding connected in series with the external battery so that it carries only the battery current. The coil is so connected that when charging current is passing it assists the winding L_1 and causes a reduction in the generator voltage, thus tending to limit heavy charging currents into a partly discharged accumulator. When the system is functioning normally, and the battery is floating, no current is passing through coil L_3, and the voltage is that of the regulator setting. If a heavy external load on the generator tends to cause discharge from the battery, the current through the coil causes the generator voltage to rise until the generator takes over the load and the battery is again floating. The winding thus exerts a stabilizing influence. It is essential to reduce sparking at the contact point to a minimum in order to maintain good voltage regulation and to reduce as far as possible the serious interference which would otherwise be caused to the operation of any nearby wireless installation. A regulator usually requires but little attention, and this would consist of cleaning and burnishing the contact points, and slight adjustment of the spring tension on the armature to compensate for wear at the contact points. When testing or adjusting a regulator the aircraft should be "run up" on the ground, and the following procedure carried out—

(i) Disconnect the battery.

(ii) See that all load circuits are switched off.

(iii) A voltmeter should be connected across the terminals to which the main positive and negative leads from the generator are attached.

(iv) Run up the engine to start up the electrical generator.

(v) Gradually increase the engine speed until a steady maximum voltage is obtained. This voltage should be 14 volts.

(vi) In order to check the operation of the regulator, increase the speed of the engine further and see that the voltage remains constant at 14 volts.

(vii) Re-connect the battery, and speed up the engine to obtain a steady operating voltage. See that the battery cut-out is closed; this will be indicated by a slight charging current shown on the battery ammeter.

(viii) Stop the engine, and see that the battery cut-out opens with a discharge current not exceeding 7 amperes.

If the above tests show that the regulator is out of adjustment, the following instructions should be carried out—

(i) Disconnect the battery leads.

(ii) Remove the small pivoted armature and the fixed contact screw.

(iii) Clean and burnish the contact faces, and replace armature and contact screw; see that contact faces are parallel after refitting.

(iv) Set the contact gap to a maximum opening of ·005 in. and tighten lock nut on fixed contact.

(v) Connect a voltmeter across yellow and blue terminals, run the generator at 4,000–5,000 r.p.m. and set regulator to 14 volts by adjusting knurled screw. Voltage adjustment should always be made with battery disconnected. When the voltage regulator arm has been removed during an overhaul, care must be taken on reassembly to ensure that the bearings are adjusted so that the arm is free to rock with just perceptible side play.

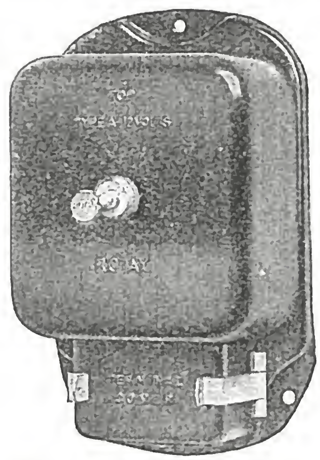


FIG. 32. "A" TYPE CUT-OUT 12 OR 24 VOLTS

Length $6\frac{1}{2}$ in. Width 4 in. Projection $2\frac{9}{16}$ in. Weight $2\frac{1}{4}$ lb.

Supplied suitable for use with either 12 or 24 volt equipment, this cut-out is suitable for loads exceeding 150 watts. It is a high-class instrument and thoroughly reliable.

(Rotax Ltd.)

Battery Cut-out

This is a device which is connected between the accumulator and the generator. Its duty is to disconnect the accumulator from the generator at all times when the voltage of the latter is below that of the former, thus preventing the accumulator from discharging itself through the windings of the generator but connecting it to the generator again when this has attained a voltage sufficiently high to ensure the passage of a charging current.

In some electrical installations on aircraft the battery cut-out is installed as an isolated item of equipment, whilst in others it is combined with the voltage regulator. The combination of the two instruments, however, merely consists of mounting them together on a common base, and under a common cover. Electrically, they are quite independent, and the

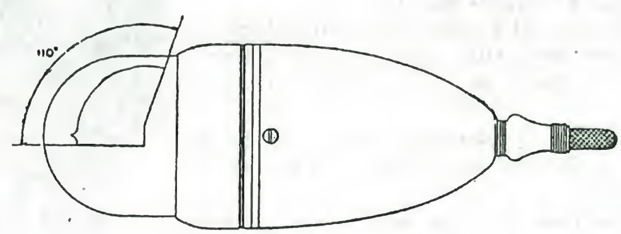
operation of one is not in any way affected by the operation of the other. For purposes of convenience, the cut-out which is normally supplied with the Mark IV voltage controller is here described.

FIG. 33. "F" TYPE CUT-OUT 12 VOLT

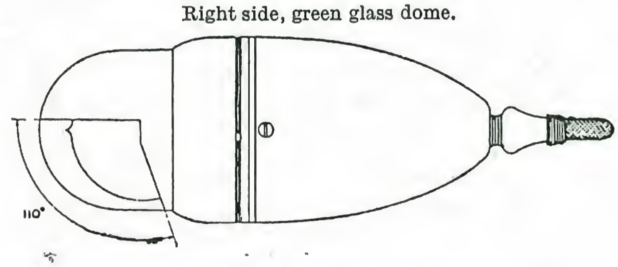
Overall length $3\frac{3}{4}$ in.
Width $3\frac{1}{2}$ in.
Projection $2\frac{1}{8}$ in.
Weight 13 oz.
This automatic cut-out is suitable for use with dynamos up to 150 watt output. (*Rotax Ltd.*)

Referring to Fig. 31, the cut-out solenoid carries two windings L_4 and L_5, L_4 being in series with the battery load, while L_5 is a shunt coil connected across the generator armature in series with the resistance R_5. When the generator is started up the contacts S_2 are open. As soon as the voltage reaches a certain value, the solenoid core attracts a small iron armature and closes S_2, thus joining the battery positive to generator positive; the battery is then connected across the generator armature through the coil L_3 on the regulator and the series cut-out coil L_4, which is wound so that it assists the shunt coil L_5. If, for any reason, a reverse current passes, due to the battery discharging into the generator, the series coil L_4 opposes the shunt coil and S_2 opens, thus disconnecting the battery.

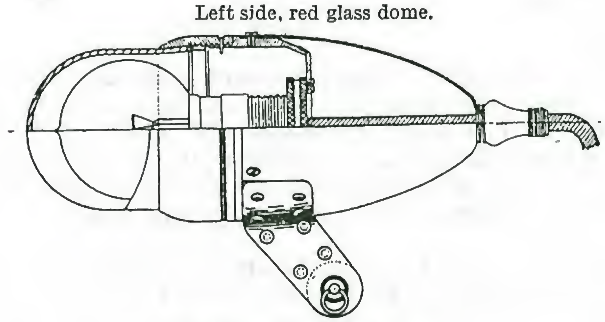
The swamping resistance R_5 is connected in series with L_5 to reduce



Right side, green glass dome.



Left side, red glass dome.



Tail lamp, white glass dome.

FIG. 34

(*By courtesy of Vickers (Aviation), Ltd.*)

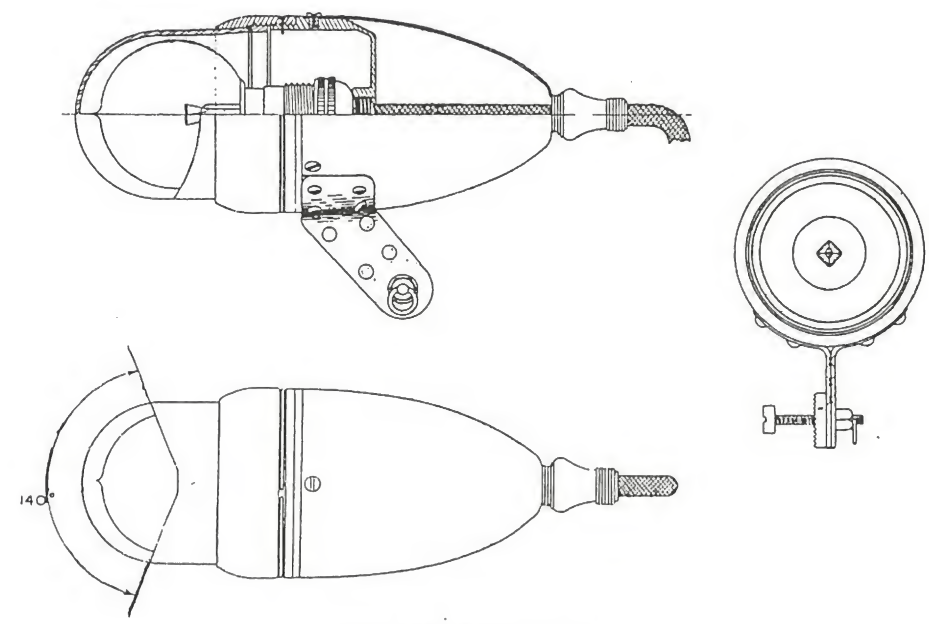


FIG. 35. TAIL LAMP
(By courtesy of Vickers (Aviation), Ltd.)

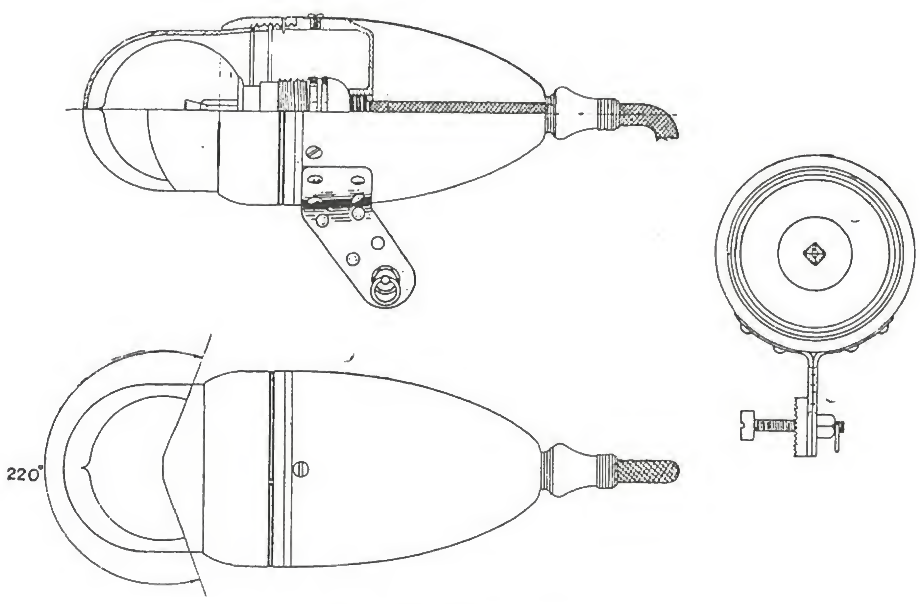


FIG. 36. HEAD LAMP
(By courtesy of Vickers (Aviation), Ltd.)

the effect of temperature variation, and ensures that the cut-out functions within the voltage limits set by the accumulator and voltage regulator. The resistance R_2 in series with L_2 is permanently connected across the generator field, and thus fulfils the purpose of the field shunt, previously employed as a separate component to improve the performance of the generator and to assist regulation.

Adjustment of the battery cut-out is carried out as follows—

(i) Disconnect accumulator.
(ii) Examine cut-out contacts, and clean if necessary.
(iii) Set contact gap to ·02 in. maximum.
(iv) Adjust the regulator to give 12 volts by means of knurled screw.
(v) Adjust cut-out control spring until contacts just close.
(vi) Re-set the regulator to 14 volts and connect accumulator.
(vii) The cut-out contacts should open with a maximum battery discharge of 7 amperes.

Navigation Lights

The International Commission for Air Navigation (October, 1928) lays down the following regulations for the lighting of aircraft at night—

For Landplanes

(*a*) *Right Side Lamp.* On the right side a green light dispersed over an angle of 110 degrees and visible at a distance of 8 km. (Fig. 34).

(*b*) *Left Side Lamp.* On the left side a red light dispersed over an angle of 110 degrees and visible at a distance of 8 km. (Fig. 34).

The lights (*a*) and (*b*) above shall be so fitted that the green light shall not be visible from the left side nor the red light from the right side.

(*c*) *Tail Lamp.* As far aft as possible a white light shining rearwards, dispersed over an angle of 140 degrees and visible at a distance of 5 km. (Fig. 35).

Tail navigation lamps are frequently installed on the trailing edges of rudders, and where this practice is adopted it is important that the effect of installing such a lamp in this position, or of changing the type of this lamp after first installation, is carefully considered in connection with recent Air Ministry requirements regarding the mass balancing of control surfaces.

Seaplanes and Flying Boats

In addition to the lights used on landplanes, i.e. the right, left, and tail lamps, the following shall be carried—

(*d*) *Head Lamp.* As far forward as possible a white light dispersed over an angle of 220 degrees and visible at a distance of 8 km. This light is to be used when the aircraft is manoeuvring on the water under its own power, and should be extinguished when the aircraft is in the air (Fig. 36).

(*e*) *Anchor Lamp.* In a position where its light can be seen in all directions at a distance of 2 km., every flying machine anchored or moored on the water shall carry a white light (Fig. 37).

(*f*) *Out-of-control Lamps.* In a position where its lights shall be seen in all directions at a distance of 3 km., every flying machine out of control on the water shall carry two red lights 2 metres apart and one over the other (Fig. 38).

Seaplanes and Flying Boats having a Wing Span of over 50 metres

The following regulations as to lighting apply to the above—

(*g*) On each lower wing tip, in addition to any other lamps required

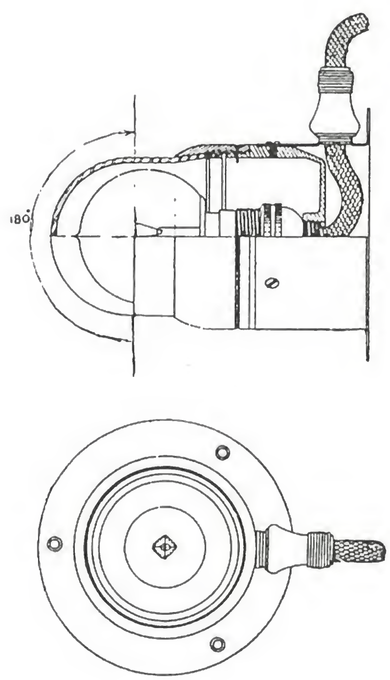


FIG. 37. ANCHOR LAMP
(By courtesy of Vickers (Aviation), Ltd.)

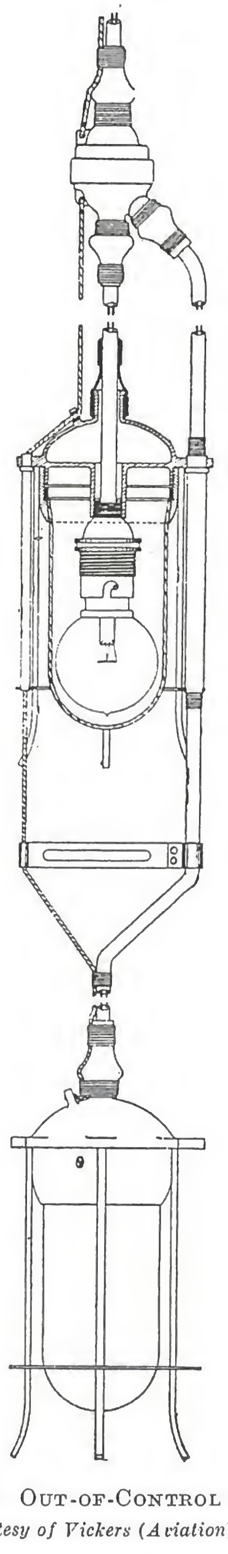


FIG. 38. OUT-OF-CONTROL LAMPS
(By courtesy of Vickers (Aviation), Ltd.)

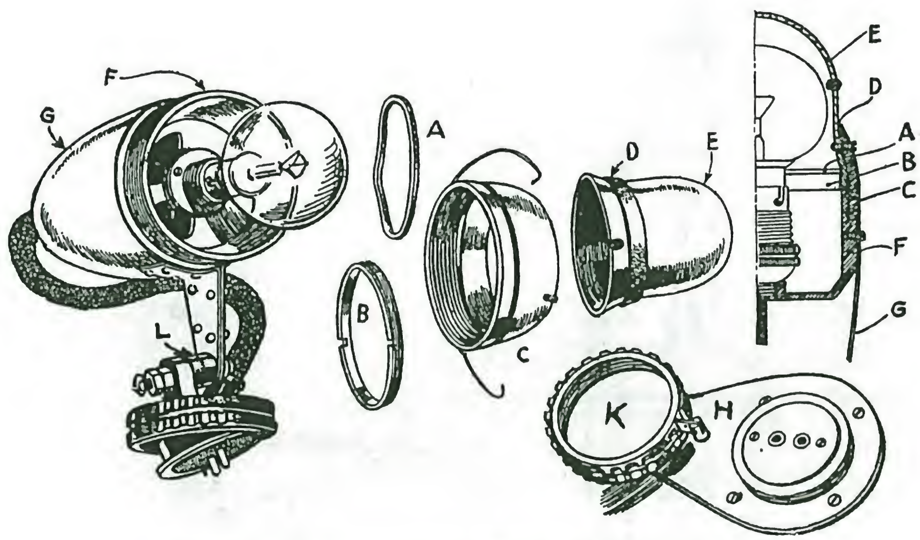


FIG. 39. VICKERS-DAVIS TYPE NAVIGATION LAMP

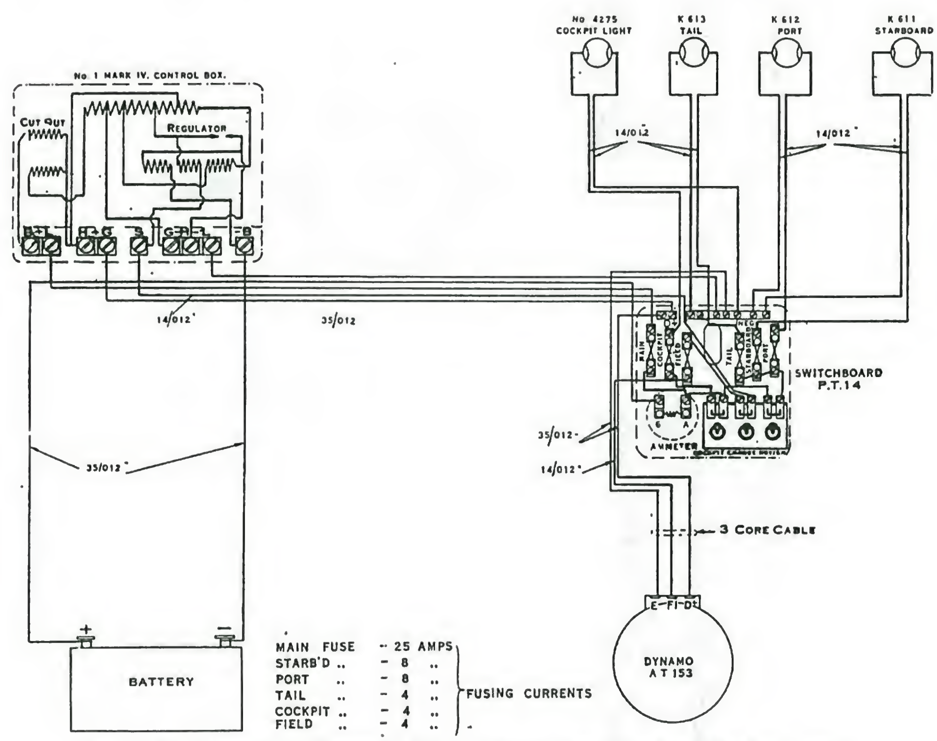


FIG. 40. TYPICAL WIRING DIAGRAM, WITH ROTAX DYNAMO AND SWITCHGEAR AND R.A.F. No. 1, MK. IV, VOLTAGE REGULATOR AND BATTERY CUT-OUT

by the regulations, a white light showing in all directions shall be carried by aircraft of such wing span when at anchor or moored on the water.

(*h*) Near the stern of the aircraft and at a height of not less than 5 metres lower than the head lamp a white light visible in all directions shall be carried by aircraft of such wing span when at anchor or moored on the water.

The anchor light illustrated in Fig. 37 conforms with the above regulations.

POSITION OF LAMPS

Right and Left Side Lamps. To be fixed at the extremity of the wing tips so as to denote the complete span. In a biplane the lamps would be fitted to the top plane when this is the larger.

Head and Tail Lamp. To be fixed so as to show the extreme length of the aircraft, or as nearly so as possible.

In certain types, such as central engined seaplane, the head lamp is usually carried on the leading edge of the wing in the central line of the aircraft.

Anchor Lamp. To be fixed to the highest point of the structure of the aircraft so that an unbroken light may be shed. The front main spar in the top centre section main plane and on the centre line of the aircraft is usually found to be the best position.

Out-of-control Lamps. To comply with the regulations, a small mast is necessary so that the lights may be seen in all directions. The lights can be plugged into a socket provided in the wiring system.

Construction and Installation

Figs. 34 to 39 show one series of lamps which has been officially approved as satisfying the regulations of the International Commission.

Head, tail, right and left side lamp bodies are all interchangeable, the only alteration to suit the position in which the lamp is to be employed being the change of the glass dome, and of the metal spinning forming the tail fairing.

The colours are burnt into the glass dome so that damp or heat do not affect them.

Fig. 39 gives the general details of the lamps, which are attached to the aircraft by a metal (aluminium or gunmetal) baseplate H by four screws or bolts and wired up to the connections shown thereon. A hinged cap screws over these connections to keep water, dust, etc., from them, and folds back when the lamp is fixed in position.

The body F and tail fairing G are made of aluminium, the dome housing G and locking ring B of duralumin.

The glass dome E is located and prevented from turning in the housing C by a grub screw, the dome being slotted to receive it.

D is a rubber band which protects the dome in its housing, the edge of the dome being further protected by another rubber ring A interposed between it and the locking-ring B. The glass dome is forced against the sloping face of the housing by screwing up the locking-ring B, which then holds it in position.

The housing ring C is screwed on the body F and locked with a circlip.

The lamps are provided with a considerable angular adjustment in a vertical plane by means of the nuts and interlocking teeth at L. No adjustment in a horizontal plane is provided and the position of the lamp in this respect is governed by the position of the baseplate H, which therefore has to be carefully regulated during its original installation.

Landing Lights

For the purpose of facilitating the landing of aircraft by night it is usual to provide on the aircraft some source of illumination under the control of the pilot, which will aid him to see whether the ground is free of obstructions and to enable him to judge his approach to the best advantage. Where flying after dark is a matter of routine the terminal aerodromes are normally equipped with adequate facilities on the ground for giving the necessary illumination, and the pilot may or may not decide to use the lights provided on his craft. Such lights on the aircraft, how-

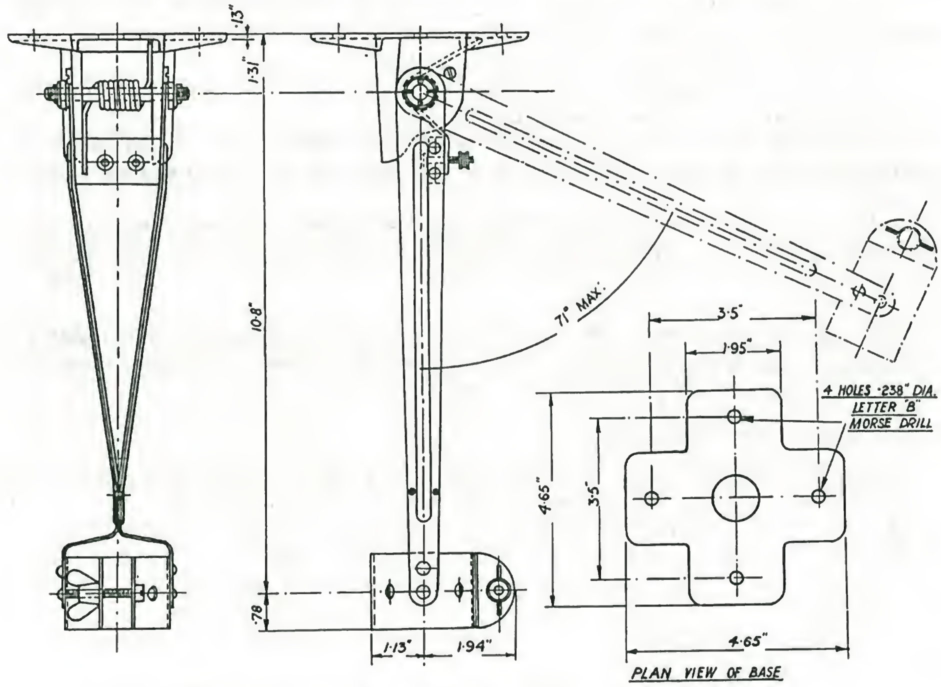


FIG. 41. BRACKET: WING-TIP FLARE, R.A.F. TYPE
(Royal Air Force Official, Crown Copyright Reserved)

ever, should always be carried and maintained in good condition, as they are liable to be required for use at any time in the case of a forced landing.

Lights provided on aircraft to facilitate night landing are of two distinct types, viz. the incandescent electric lamp type, and the pyrotechnic, or flare type. The former have the advantage of being under the control of the pilot at all times, and to be free from dazzling effects. On the other hand, their field of illumination is restricted, they are heavy, and they require a large supply of current. They may be mounted almost anywhere on the aircraft, either externally on brackets, or internally behind a suitably placed "window." They may be fixed to throw a beam in one direction, or they may be mounted on trunnions so that the pilot, by means of suitable remote control gear, may direct the beam at will anywhere within a somewhat restricted field. The lamps require a heavy supply of current, and in order to avoid loss of illumination at a critical moment, such as during a slow glide in to land, it is essential to include an accumulator in the electrical system and not to rely solely on a generator, where output would diminish with loss of speed.

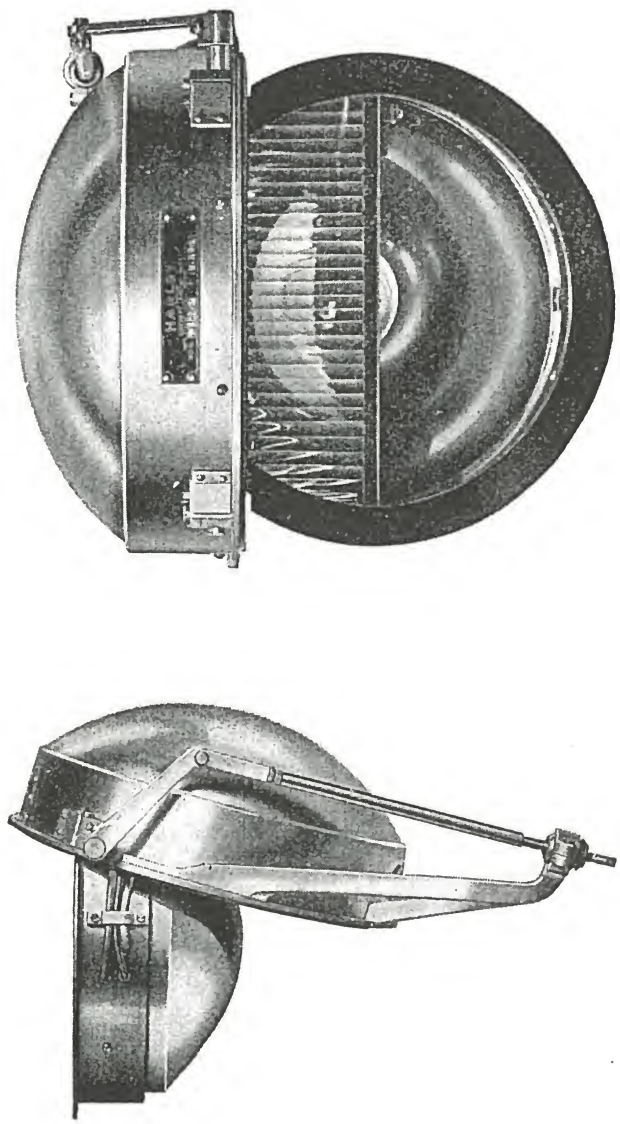


Fig. 42

One approved lamp of this type is the Harley (Figs. 42 and 43), which may be obtained with either 6 in., 8 in., or 11 in. diameter reflector. Most types of Harley lamps incorporate a patent spring clip case which can be opened in a few seconds for bulb replacement, etc. The front assembly, containing the front glass, lenses, and rubber cushion is the fixed part of the lamp to which the brackets or fittings for mounting are attached. The rear assembly consists of the reflector, bulb, and tension elements for holding the two portions together. In lamps of the vertical dipper type, for the nose fairing of an aircraft, when access to the rear of the lamp is rendered difficult, a casing having a removable front glass is used. The front glass, which is paste sealed, is further secured by a face plate which has a rubber

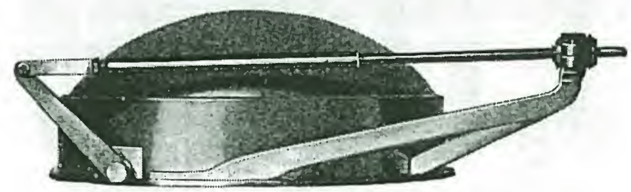


FIG. 43

cushion to abut the nose fairing and is positioned by six set screws. The reflector and lenses are set at a number of degrees (6°–9°) to the face plate and hinge assembly to obtain the correct offset of beam when the said face plate is square with the machine. The lamp is hinged at the bottom and dips in a vertical plane forward.

The wiring lay-out should be the shortest possible to reduce voltage drop. The switch should be placed conveniently near the battery or solenoid switching introduced. Cables should be selected to give a minimum voltage drop for weight, e.g. 110/36 cable to B.S.I. 5002. A fuse of double the bulb amperage should be incorporated in the system.

All lamps of this type normally give a wide spread beam with deep vertical section. The lamp bulbs used may be for 12-volt or 24-volt systems, single or double filament, and vary from 144 watts to 960 watts consumption and a life varying from 30 hours to 100 hours, but replacement should be carried out at approximately half the life.

The battery must be kept in perfect condition, especially if a generator is in circuit, to prevent the possibility of the filament being overloaded and burnt out. In lamps of the double filament type the main and auxiliary filaments should never be lighted together. The special switch supplied by the makers is designed to prevent this.

The pyrotechnic, or flare type of landing light, has the advantage of greatly increased illumination, low weight, simple installation, and negligible current requirements, together with an unrestricted field of illumination. Their disadvantage, however, lies in the fact that, once ignited, they must be allowed to burn themselves out. They are also liable, if not carefully installed and shielded, to dazzle the pilot and thus actually increase the danger of a landing by night. The normal method of installation is to mount the flare in a hinged bracket secured under the lower

plane towards the wing tip (Fig. 41). Special attention is directed to the Air Ministry Notice to Aircraft Owners and Ground Engineers No. 30 of 1934.

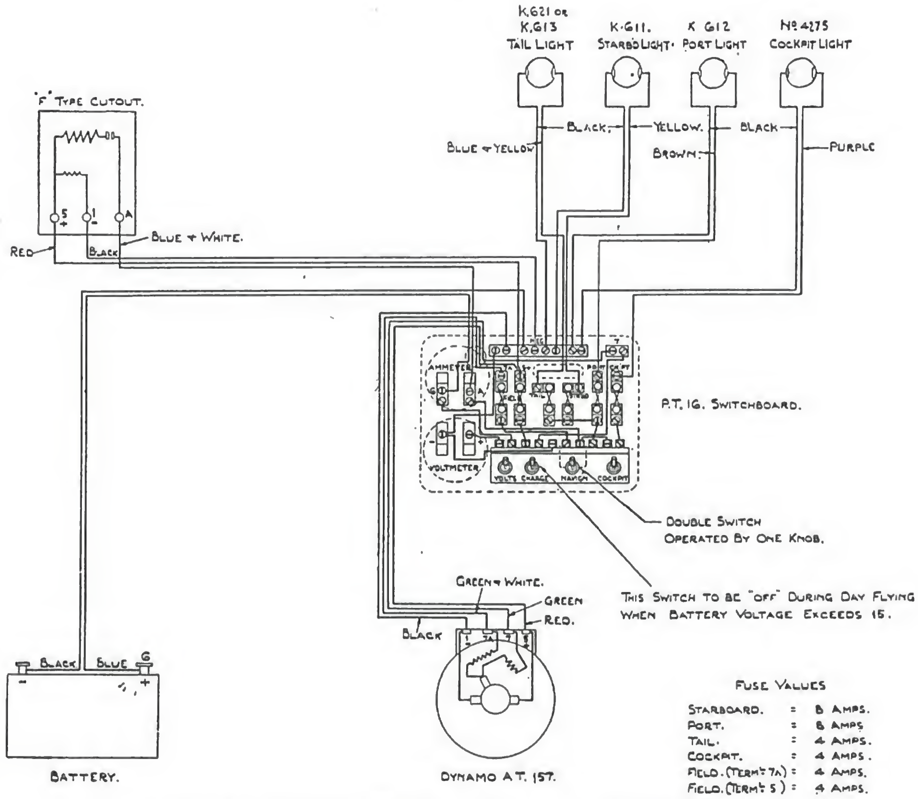


FIG. 44. TYPICAL WIRING DIAGRAM—ROTAX UNITS

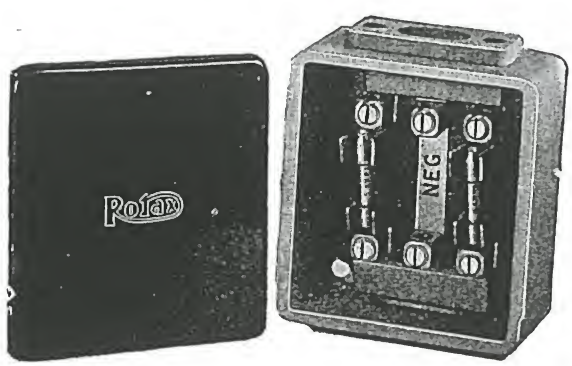


FIG. 45. TYPE G 2-WAY FUSE BOX

Length $3\frac{7}{16}$ in. Width $2\frac{15}{16}$ in. Height $1\frac{3}{8}$ in. Weight 9 oz.

Fuse Boxes

These are safety devices introduced into a wiring system to eliminate risk of fire on an aircraft, and damage to equipment as a result of the

occurrence of a short-circuit on the wiring system. It is always desirable to install a main fuse in both poles of the main circuit close to the source of power—the generator, in those cases where no accumulator is carried, and the accumulator, in those cases where only an accumulator or both an accumulator and a generator are carried. In the event of a short-circuit occurring between the main poles of a generator circuit the usual result is a momentary rush of current, followed immediately by loss of excitation of the generator, and consequent decrease or interruption of the generator current. In the case of a short-circuit occurring between the main poles of an accumulator circuit, however, the rush of current is sustained, and the consequent danger of fire is very considerably increased. In addition to the pair of main fuses, it is also desirable to subdivide the whole electrical system on the aircraft into sections, and to fuse each section separately.

FIG. 46. P.T.12 SWITCH BOX

Length $11\frac{1}{2}$ in. Height $6\frac{3}{8}$ in. Depth (overall) $2\frac{15}{16}$ in. Weight $8\frac{1}{4}$ lb.

This is similar in construction to the smaller P.T.14 type, but provides extra controls for the increased number of circuits necessary with large passenger-carrying aircraft. A voltmeter is fitted in addition to the central zero type ammeter, as will be seen from the illustration.

(*By courtesy of Rotax Ltd.*)

In the case of sectional fuses, however, it is permissible to provide a fuse in one side of the circuit only. Both main and sectional fuse units must be of the totally enclosed type, that is to say, the length of fuse wire must be totally enclosed in some form of container which will prevent any danger arising from the heating and melting of the wire. Spare fuse units should be carried in some convenient place on the aircraft, and all fuses should be clearly marked with the current at which they are designed to operate. The capacity of a fuse should be from 10 per cent to 50 per cent in excess of the total current which might be expected to flow through it under normal circumstances, i.e. with all legitimate load switched on, the larger margin of 50 per cent being allowed in the case of lightly loaded circuits, and the 10 per cent margin in the case of heavily loaded circuits. The relationship of the total possible legitimate load to the safe carrying capacity of the wire concerned should also be taken into account in determining the margin of fuse capacity which should be allowed.

FIG. 47. P.T.14 SWITCH BOX
Length $5\frac{1}{2}$ in. Depth $1\frac{23}{32}$ in. Height $5\frac{1}{2}$ in.
Weight 2 lb.

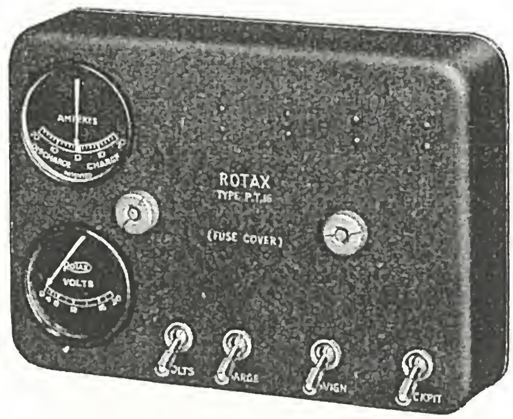


FIG. 48. P.T.16 SWITCH BOX
Length $7\frac{1}{2}$ in. Depth $1\frac{3}{4}$ in. Height $5\frac{5}{8}$ in.
Weight 3 lb.

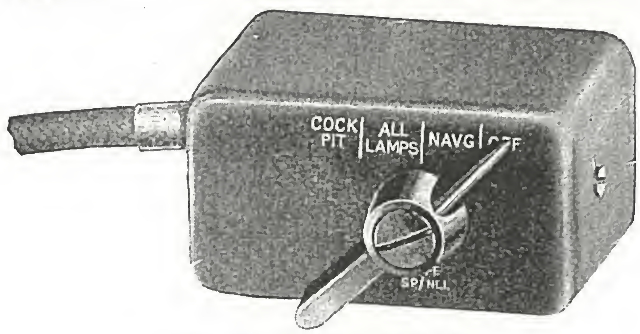


FIG. 49. SP/NLI SWITCH
Length $2\frac{13}{16}$ in. Depth $1\frac{13}{16}$ in. Height $1\frac{9}{16}$ in. Weight 9 oz.
(*By courtesy of Rotax Ltd.*)

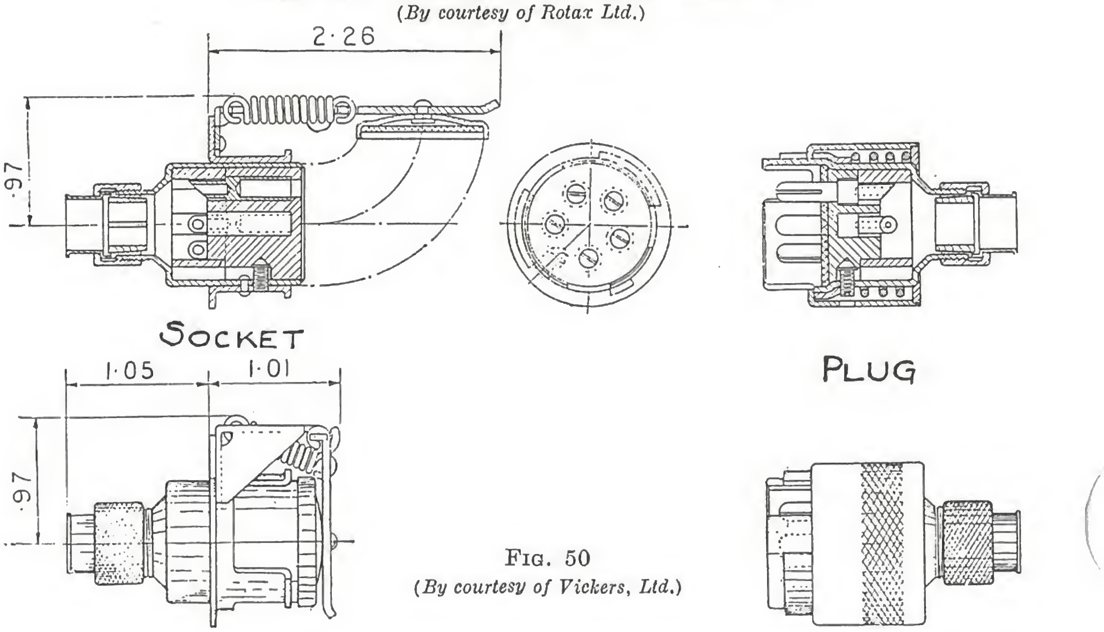


FIG. 50
(*By courtesy of Vickers, Ltd.*)

Plug and Socket Connectors (Fig. 50)

A plug and socket connector, manufactured and marketed by Messrs. Vickers, and constructed to Air Ministry design, has been developed to meet the demand for a device to enable electrical connections to be rapidly made or broken, and especially to enable items of electrical equipment to be rapidly removed from, or restored to, aircraft, without the usual laborious manipulation of cable connections to terminals. A particularly useful application is at the wing root joints on aircraft fitted with folding wings, where connections to wing tip flares and navigation lights have to be broken whenever the wings are folded.

Provision can be made for the entry of various types of cables, by using suitable collets. The five-pin and two-pin bases are interchangeable. The plug portion is detached from the socket by a spring controlled bayonet lock; the socket portion is then made weatherproof by throwing over a spring loaded cap. The plugs are supplied in either duralumin or bronze, the latter being specially suitable for seaplanes and flying boats.

Smith's Petrol-contents Gauge.

Mk. 1. This gauge was developed with a view to meeting the demand for a petrol-contents gauge reading direct on the instrument board, and free from the disadvantages attendant on gauges which depend on air pressure and metal tubing or mechanical transmission mechanism for their operation. Ability to cope with very long transmission distances was also a prime requirement.

The principle is extremely simple. A tank unit comprising a light but rigid structure, made up of an aluminium tube with the requisite end castings, carries at one end a bevel gear (or occasionally a spur gear) which communicates the movement of a float arm to a vertical or occasionally a horizontal spindle. Through a long gland the spindle enters an enclosed chamber formed of bakelite mouldings, into which are built an electrical resistance and a collector ring. Three terminals emerge from this chamber, connecting respectively with the ends of the resistance and with the collector ring. The distribution of electrical resistance between these terminals depends upon the position of a rheostat brush which forms a bridge between the collector ring and the resistance. The brush is connected to the spindle and, through the medium of the gearing, its position is varied according to the position of the float in the tank. An indicator of special design is so arranged that its pointer takes up a position which depends upon the distribution of resistance between the three terminals emerging from the tank unit. It only remains to connect the system, through a push-button, to a 6-volt or 12-volt circuit to complete the installation. It will be obvious that by the use of multi-way switches several tanks can be brought in turn into electrical connection with the indicator if it is desired to save space on the dashboard.

It will be obvious that for a fuel-contents gauge to operate over the complete range from completely full to absolutely empty there must be space for the float to move up or down into these positions, with due allowance for the space which the float must occupy. Since the registration of the top few gallons is not of practical importance, there is no need to provide a bump on the top of the tank. At the bottom of the tank, however, where the registration of the last few gallons of fuel can make all the difference between a forced landing and reaching a safer landing-ground, it will be obvious that there will be many occasions when a sump is essential. There are also certain official minimum requirements to be met.

The indicator is an electro-magnetic device which employs a special circuit to move a small soft-iron armature (see Fig. 51A).

The two coils A and B are wound on a single special low-hysteresis iron former, and are so arranged that when the contact F is at the mid-point of the potentiometer E, current passes through both coils and maintains the armature D in a horizontal position. When the sliding contact F is moved to either the left or right of the mid-point of the potentiometer E, then current passes through the coil C. By proper arrangement of the polarities of the electro-magnetic coils A, B, and C the armature D can be made to move to the left when the contact F is moved to the left, or vice versa. This is because the sense of the direction of the windings, clockwise or anti-clockwise, for any given sense of the flow of the currents decides the magnetic polarity. Thus, with the contact F in the mid-position on the potentiometer E, the polarities of the coils may be as shown in Fig. 51B. In this case the resultant force on D is horizontal, and the indicating pointer attached to D stays in the middle of the calibration scale.

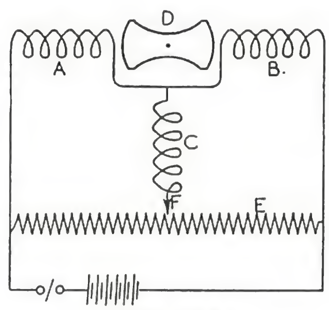


FIG. 51A

When the contact F is moved to the left, the current through A decreases while that through B increases, and a current passes through C

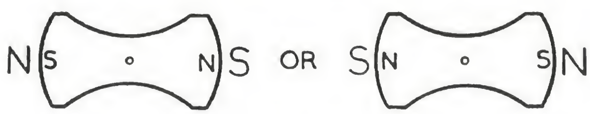


FIG. 51B

in such a direction that the magnetic polarities of B and C are the same, and the armature will rotate in a clockwise direction (Fig. 51C).

If the contact F is moved to the right, the current through A increases while that through B decreases, and a current passes through C in such a direction that the magnetic polarity of A and C is the same, and the armature will rotate in an anti-clockwise direction (Fig. 51D).

The extent of rotation depends upon the disposition of the soft-iron

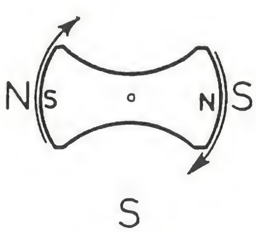


FIG. 51C

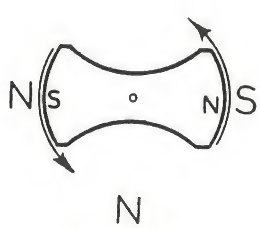


FIG. 51D

cores, the ampere-turns on each coil, and the values of the resistances of the coils, A, B, and C, and the potentiometer E.

The contact F is operated through gears from a movable arm carrying a float in the petrol tank. Owing to the fact that the iron cores in the instrument are not magnetically saturated and that the air gaps are relatively large, the instrument is practically independent of variation in battery voltage.

Coils A and B are together known as the **control coil** and tend to make the pointer stay in the mid-position of the calibration scale. Coil C is known as the **deflecting coil** and tends to make the pointer move away from the mid-position.

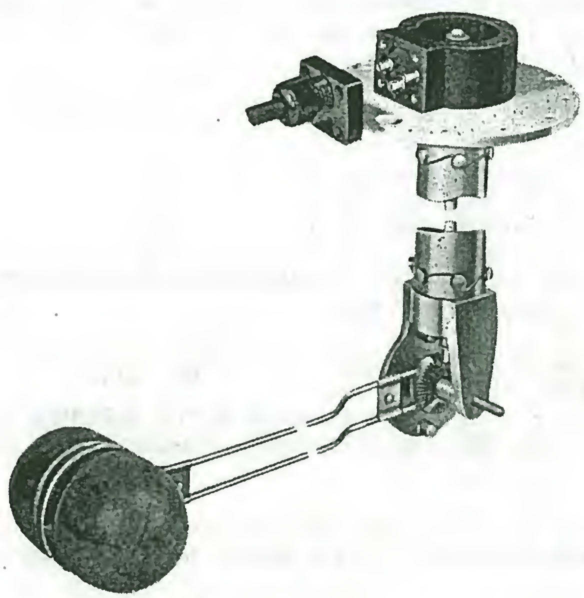


Fig. 51E. Tank Attachment (Mk. 1)

The **tank attachment** consists of a doped cork float carried on an arm which is connected by a pair of bevel or spur gears to a vertical spindle (51E). To the top of this spindle is attached the contact arm F, travelling over the potentiometer, of which the resistance is about 90–94 ohms. By means of this device varying voltages are applied to the deflecting coil of the instrument, causing the pointer to deflect in accordance with the height of the fuel in the tank.

The **gauge** comprises the coils A, B, and C, and the armature D in a circular metal case, with a pointer and dial (Figs. 51F and G). The total angular rotation of the pointer is 75°, or $37\frac{1}{2}$° on either side of the mid-point. The approximate resistance of coils A and B is 47 ohms for each half, and of coil C 41 ohms.

Fig. 51F

The **switch** consists of either a push-button switch for single tanks, or a combined multi-way selector switch and push-button for aircraft with more than one tank (Fig. 51H). The selector switch has a snap-over action, and the push-button has a spring return to the off position. The **cable** is special petrol-proof three-core cable, one end being sealed in a three-point plug, which is connected to the tank attachment either by four screws, or in certain cases by means of a quickly removable two-prong pin, which can easily be locked in position.

It is necessary to design the tank unit to suit the dimensions of the particular tank in which it is to be installed. The movement of the potentiometer arm F has been standardized to approximately 270°; in

order to keep this angle different gear ratios are used, so as to give various angular movements for the float arm. This, together with the fact that the length of the float arm and bracket may be varied, gives the gauge wide adaptability. For the purpose of **calibrating,** the aircraft is set up in the normal flying attitude. The tank attachment is mounted in the tank and connected to the panel meter through the switch and battery. In order that a permanent record of the calibration voltages may be kept, a voltmeter of high internal resistance—1,000 ohms per volt—is connected across B + and P terminals on the back of the meter. Petrol is then poured in the tank in measured quantities and the meter calibrated at convenient points—usually multiples of ten—voltages being taken at each calibration mark. The voltage across meter terminals B + and B – should be taken and recorded (when the instrument is switched on) both at the beginning and at the end of the test. If required, this procedure is repeated with the aircraft in the tail-down position, the marks in this case being made on the upper side of the scale.

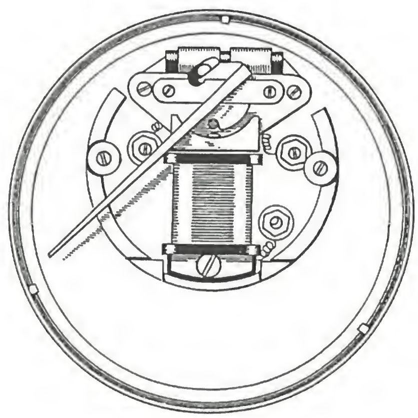
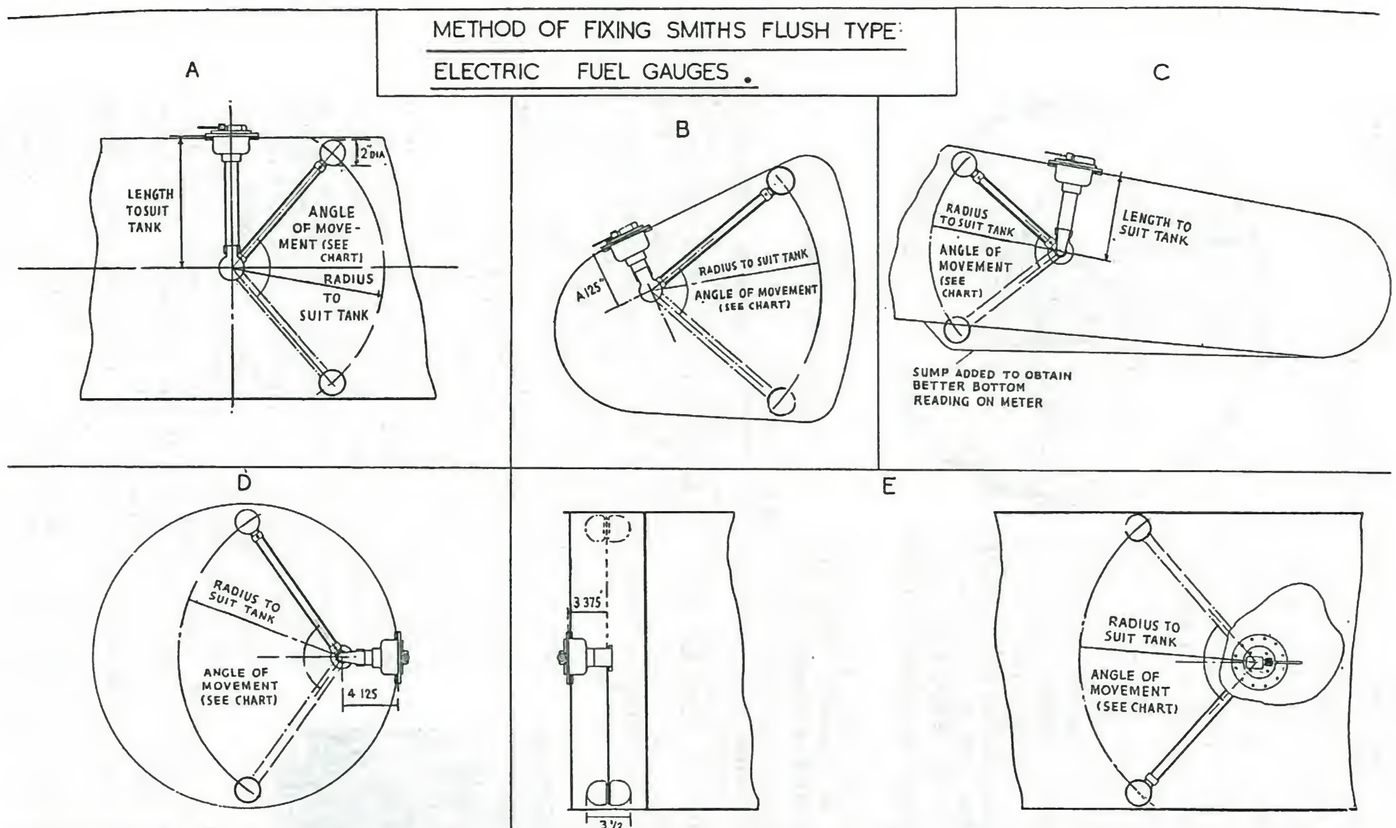


FIG. 51G
GAUGE: INTERNAL VIEW

During installation it is necessary to bear the following important points in mind. The instrument must be handled carefully at all stages before actual fitting. Any distortion or bending of the arm will cause incorrect indication on the meter. If possible, try the movement of the float arm in the tank before actually screwing down the tank attachment, in order to make certain that there is no fouling at either top or bottom, or on any baffle or skin stiffener. The tank attachments must be carefully made with the Langite washer supplied, a suitable jointing compound being used. Sharp bends must be avoided in the cable, particularly where it leaves the tank attachment cable clamp. The cable must be securely supported throughout its length, especially at any point where connections are made to terminal blocks, the switch, or panel meter. If the cable is run in tubes, these must be rigidly held, especially at the ends, as otherwise vibration may cause fracture of the wire. The meter must be set vertically in the dashboard. It is calibrated in the "tail on ground" and "normal flight" attitudes for land machines, and "afloat" and "normal flight" for seaplanes and flying boats. Normal flight corresponds to that attitude of the machine when the fore-and-aft level reads zero. It is useless to read the gauge unless the machine is in this definite position when in the air. The part number of the tank attachment is stamped on the flange, and that of the meter engraved at the extreme top of the dial. It is essential to see that these numbers agree with those shown on the tank drawing or equipment sheet. Wiring diagrams are supplied with every installation, and must be adhered to for the method of wiring. Great care must be taken, when either

FIG. 51H



	A	B	C	D	E
ANGLE OF MOVEMENT OF FLOAT ARM	64° 98° 80° 108° 118°	64° 98° 80° 108° 118°	64° 98° 80° 108° 118°	64° 98° 80° 108° 118°	73° 96° 80° 104° 88°
POSITION OF CABLE	ANY POSITION				
DISTANCE FROM UNDER-SIDE OF FLANGE TO CENTRE OF GEARS	TO SUIT TANK	MINIMUM LENGTH 4 125"	TO SUIT TANK	MINIMUM LENGTH 4 125"	MINIMUM LENGTH 3 375"

J.

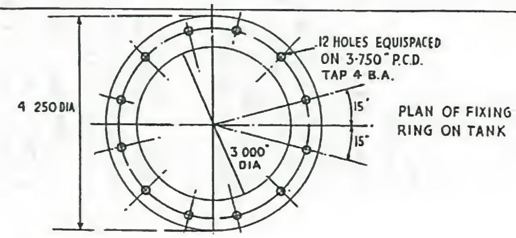


FIG. 51J

connecting up or disconnecting the gauge, to see that the terminal P (the white wire) is not short-circuited to either B+ (the red wire) or to $B-$ (the black wire). If the meter pointer reads above the zero mark when the tank is empty or below the maximum reading mark when the tank is full, it indicates that the float arm is not coming up against the stops on the tank attachment, and may be due to the arm fouling on the bottom or top of the tank, or touching a baffle or stringer because the arm has been bent. In an installation having two or more identical tank attachments reading on one meter by means of a selector switch, it is essential to see that the tanks are set up correctly in the aircraft, as otherwise the meter will not give the same reading for all tanks, even though in fact they contain an equal amount of fuel. When attempting to **locate faults** it may be useful to remember that if the electrical lead to the potentiometer arm contact (the white lead) is broken, the meter pointer will read vertically. If the electrical lead to that end of the potentiometer which the contact arm reaches when the tank is full (the blue lead) is broken, the indication on the meter will only be correct when the tank is empty, reading low in all other cases by an amount which increases with the tank contents, the readings actually being confined to the lower half of the scale. If the electrical lead to that end of the potentiometer which the contact arm reaches when the tank is empty (the red lead) is broken, indication on the meter will only be correct when the tank is full, reading high in all other cases by an amount which increases as the tank contents decrease, the readings actually being confined to the upper half of the scale.

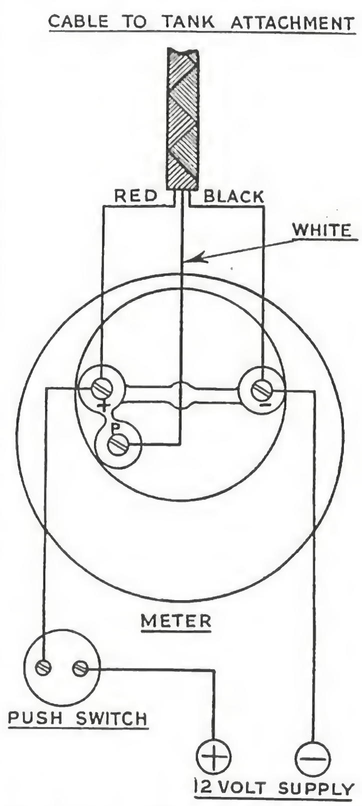


FIG. 51K. WIRING DIAGRAM: ONE TANK PER GAUGE

Fig. 51J shows examples of the various ways in which attachments can be mounted in tanks of differing shapes and capacities. Not only are various alternative lay-outs illustrated, but also limiting values for important dimensions within which, in the interests of standardization, manufacture has been confined.

MK. IV. Although large numbers of the earlier types of equipment are still giving satisfactory service, Messrs. Smith's have introduced many major modifications into their more recently issued equipments, which are now known as the Mk. IV type. Their sphere of usefulness has also been extended to include dashboard instruments for indicating the position of flaps, retractable undercarriages, and other devices requiring a remote indicator. As compared with previous types, the new equipment can be supplied for operation either by 12 or 24 volts, and the accuracy attained shows a greater independence of voltage and temperature. It is designed to give continuous readings; but although a suitable selector switch can be provided to enable readings (e.g. of the contents of more than one fuel tank) to be obtained on a single indicator, separate indicators for each transmitter unit are preferable, thus eliminating the selector switch.

IMPORTANT

1. GREAT CARE MUST BE TAKEN WHEN EITHER CONNECTING UP OR DISCONNECTING THE GAUGE THAT THE TERMINAL P (OR WHITE WIRE) IS NOT SHORT CIRCUITED TO EITHER B+ OR -VE OR TO THE RED OR BLACK WIRE NEGLECT OF THIS PRECAUTION MAY RESULT IN THE POTENTIOMETER BEING BURNT OUT

2. ON NO ACCOUNT SHOULD THE FLOAT ARM BE BENT OTHER THAN AS SUPPLIED THE FLOAT ARM PROVIDES BOTH TOP AND BOTTOM STOPS WHICH PREVENT THE CONTACT ARM OVER TRAVELLING THE POTENTIOMETER

TWO WAY SELECTOR SWITCH

SWITCH POINTER POSITION	TERMINAL SELECTED
10 O'CLOCK	2
2 O'CLOCK	1

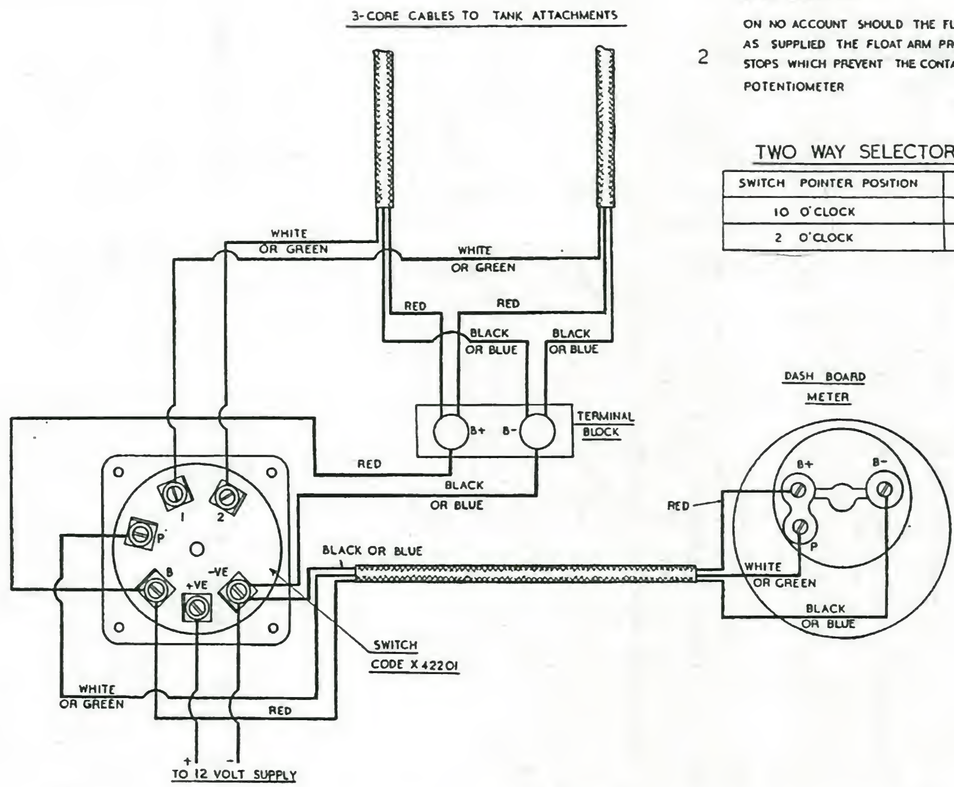


FIG. 51L

The shape of the new indicator is more convenient than that of earlier models, and in spite of a reduction in overall size the length of the scale has been increased to $4\frac{1}{2}$ in., owing to the extended arc.

The dial design of the standard indicator is dependent on the function for which it is required. The actual form of the transmitter also depends on its particular application, but the element itself consists of a complete circular resistance on which two brushes make contact at diametrically opposite points. The movement which is to be remotely indicated controls the rotation of the brushgear, the latter being accurately followed by the indicator pointer. Because of the unavoidable friction which occurs between the resistance and the brushes, a certain amount of power is required to operate the system. That this power need only be slight, however, is shown by the fact that the device is successfully applied as a fuel-contents gauge, in which case it is geared to the usual Smith float mechanism. The transmitter is built into a bakelite moulding which can be fitted in several types of housing. It consists primarily of a circular or toroidal resistance tapped at three equidistant points, connections being taken from these points to the indicator. Current is fed into the resistance at two diametrically opposite points by a pair of brushes, mounted together and capable of unlimited rotation, although normally less than 300° is used. This brush assembly is geared to the mechanism, the position of which is to be shown on the indicator. The equipment is of robust construction and has adequate insulation. The terminals are of the approved shrouded type throughout, the binding screws having captive washers. A moulded cover protects the terminals and clamps the cable when in place. The indicator mechanism, which is similar to a small motor, has a slotted stator of normal form, carrying a distributed three-phase Y-connected winding. The rotor is a simple two-pole permanent magnet carried on a spindle turning freely in jewelled bearings, and the assembly is made in a pressed-steel shell forming both a rigid frame and a complete shield to prevent magnetic leakage from affecting other instruments. This complete assembly is housed in a moulded case which has a standard $2\frac{1}{2}$ in. square flange and is closed with a window of non-splinterable glass. A terminal block with cover is provided at the back of the instrument. The three tappings on the transmitter resistance are joined by cable to the ends of the Y-connected indicator winding, and as the brushes in the resistance are rotated it will be obvious that the current distribution in this, and in the indicator coils, will change both in magnitude and in sign, with the result that the indicator rotor and pointer follow the brush movement through 360° or more if required. Pointer and rotor are accurately balanced, so that if the supply is switched off, the pointer remains in the position to which it was deflected. In fuel gauges particularly this is a disadvantage, and it is overcome by the inclusion of a magnetic pull-off device to bring the pointer to a blank part of the scale when the current supply is interrupted. Unfortunately, this slightly spoils the uniformity of the scale and the otherwise perfect voltage compensation of the equipment. When the apparatus is applied to fuel-contents gauging on a 24-volt electrical supply, two resistances are inserted in the battery leads to limit the current in the case of an accidental short circuit.

The simple electrical circuit is shown in Fig. 52, from which it will be seen that it is the practice to take the battery leads to the indicator, and a five-core cable from the indicator to the transmitter. The equipment is designed for continuous operation, the current consumption being approximately 0·3 ampere at 12 volts, or 0·15 ampere at 24 volts, except when

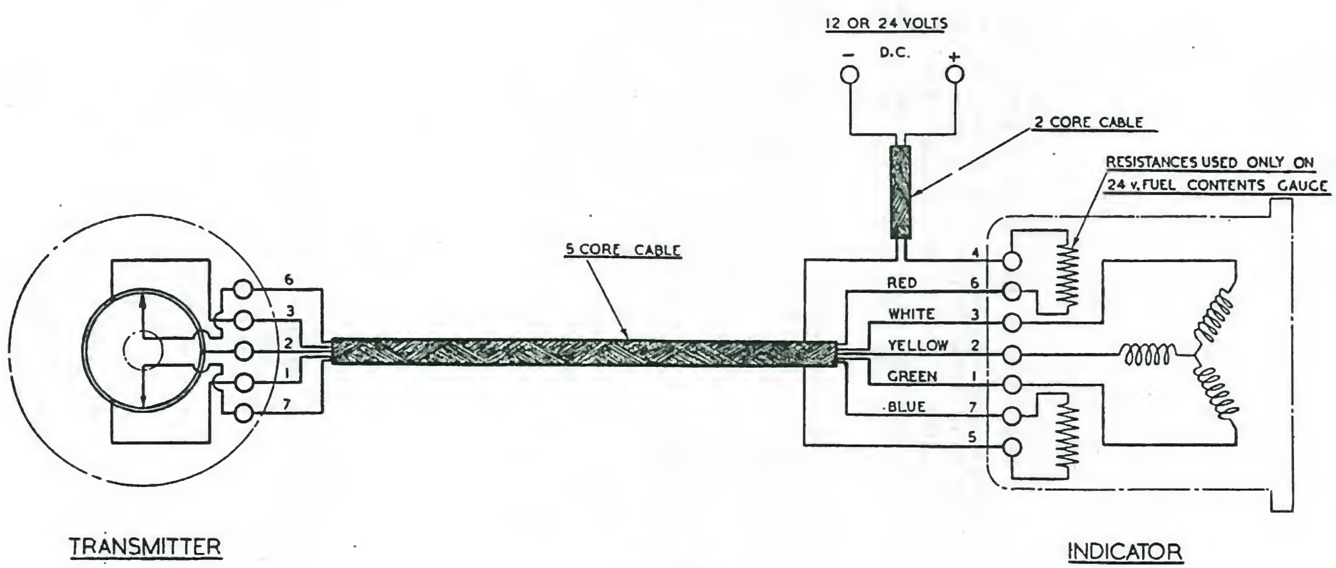

12 OR 24 VOLTS
D.C.
–
+
2 CORE CABLE
RESISTANCES USED ONLY ON
24 v. FUEL CONTENTS GAUGE
5 CORE CABLE
6
3
2
1
7
4
RED
6
WHITE
3
YELLOW
2
GREEN
1
BLUE
7
5
TRANSMITTER
INDICATOR

FIG. 52

applied as a 24-volt fuel gauge, when the current is 0·3 ampere. The instrument is voltage-compensated over a wide range, its accuracy remaining unaffected by the length of connecting cable within reasonable limits. It will be noted from the electrical circuit diagram that a five-core cable is needed to connect the indicator to the tank attachment, the terminals of both of these being clearly numbered. When the wiring, with the exception of the battery leads, has been completed, the whole installation should be tested with a Megger to determine the insulation to frame. A value of less than 5 megohms cannot be accepted, and if such a low value is found, it will be necessary to test the wiring in sections to find the fault. It is possible that the connecting cable may be damaged in service, or wrong connections made during installation or repair, and the following notes are intended to assist in the diagnosis of any trouble.

(1) If the pointer remains in the "pull-off" position at 6 o'clock when the current is switched on with the tank empty, this may be due to—

(*a*) Broken lead in battery circuit, or between the terminals numbered 7 and 6 on indicator and transmitter.

(*b*) Broken connection between No. 3 terminals.

(*c*) Broken connection between No. 1 terminals.

To determine the existing fault, fill the tank and note the pointer movements during the process. If pointer remains at 6 o'clock—Fault (*a*). If pointer moves from 6 o'clock to zero and back—Fault (*b*). If pointer remains stationary for some time, suddenly moving to half-full and eventually returning to 6 o'clock—Fault (*c*).

(2) If pointer moves to zero when current is switched on, but rotates in the wrong direction as the tank is filled to the three-quarter point, ultimately coming back to zero, this is caused by a broken lead between terminals 2.

(3) If pointer takes up a position about half-full and rotates in the right direction as the tank is filled, keeping 180° in front of its correct position, the fault is the result of the reversal of the battery leads or crossing of connections between terminals 6 and 7.

(4) The indicator connections and the transmitter can be connected up in six different ways, of which only *one* is correct. The wrong order will result in a changed zero position of 120° in either direction, or in reverse rotation.

(5) If, after many hours' flying, the indicator pointer shows a tendency to oscillate between some reading and the off position, it is an indication that the potentiometer has become dirty or that the brushes are not pressing sufficiently hard upon it. To rectify this defect the resistance can be easily removed, but in no circumstances should the float arm be caused to move whilst the resistance element is dismounted. If this precaution is taken, there will be no difficulty in getting the operating arm to engage with the brushgear, because the resistance unit has a projecting pin which enters the corresponding hole on the flange. Make sure that all the fixing screws are done up tightly again to ensure a petrol-tight joint. To ensure interchangeability in equipment supplied for one type of aircraft, the gauges are inspected to verify that the readings are within 3 per cent of those obtained in the original calibration, no positive error being permitted below 30 per cent of full scale. It should be noted that the standard tank attachment is designed to enter a 3-in. diameter hole and to be secured by twelve equally spaced 2 B.A. holes on a 3·75-in. P.C.D. If it should be necessary, however, the tank attachment flange may be designed to suit a particular hand hole. The angle through which the

float arm moves should be 98°. This angle has been standardized, but in cases of real difficulty the following angles are also suitable—

Mk. IV Tank Attachment: 63·0°, 80·2°, 94·5°, 101·3°, 115·0°. Mk. III and earlier types of tank attachments: 64°, 80°, 90°, 104°, 108°.

Revolution Indicators (Electrical)

A mechanical revolution indicator requires a rotary drive reaching the full distance between the engine and the indicator. When the distance is great, serious difficulties are encountered, and strains are set up in the drive which cause jerky and inaccurate readings. The development of

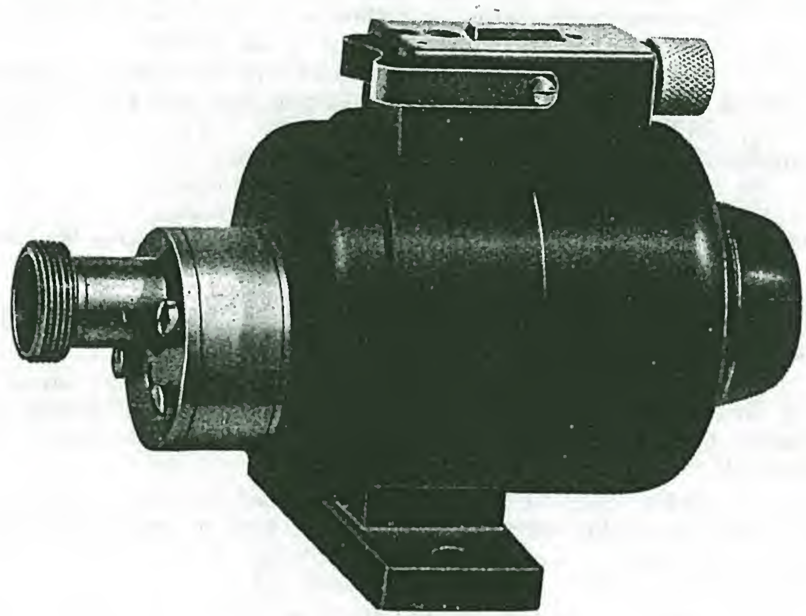


Fig. 53
(By courtesy of the Record Electrical Co., Ltd.)

large aircraft, therefore, renders the use of mechanical indicators impracticable.

The Record Electrical R.P.M. Indicator, which consists of two separate parts, the dynamo or generator, and the voltmeter or indicator, is not subject to these disadvantages and limitations. It has no complicated moving parts, its accuracy is not affected by mechanical wear, and it gives smooth and responsive indications.

The generator is placed near the engine and should be connected to the selected driving shaft by the shortest means of coupling. An electric current is generated proportional to the speed of rotation, and the current is led to the indicator by a pair of insulated wires. The indicator, therefore, can be placed almost any distance away, the resistance of the leads being negligible.

The indicator is a moving coil voltmeter of special construction to meet the exacting requirements of aircraft work. It is calibrated in terms of engine speed.

The Record R.P.M. Indicator is manufactured to Air Ministry specifications for military and civil aircraft.

Every indicator and every generator is standardized for use with any

Record indicator, of whatever type, and thus the stock of spares it is necessary to carry is greatly reduced. For example, a spare triple edgewise indicator would require three generators, one for each dial if individually calibrated, but by standardizing, one spare generator is sufficient. Moreover, the individual units of the edgewise type of indicator are themselves

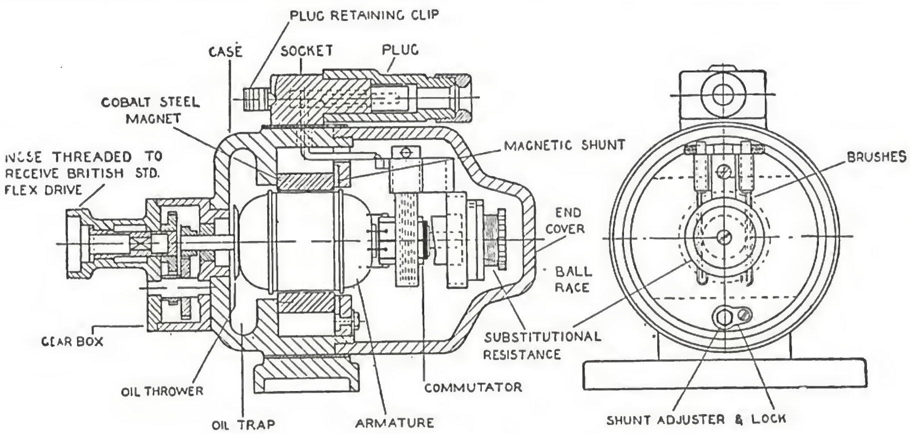


FIG. 54

(By courtesy of the Record Electrical Co., Ltd.)

mechanically and electrically interchangeable, which again reduces the stock of spares. The "Cirscale" type is also interchangeable with the edgewise type.

The generator is remarkably small, yet a real power unit (Fig. 53),

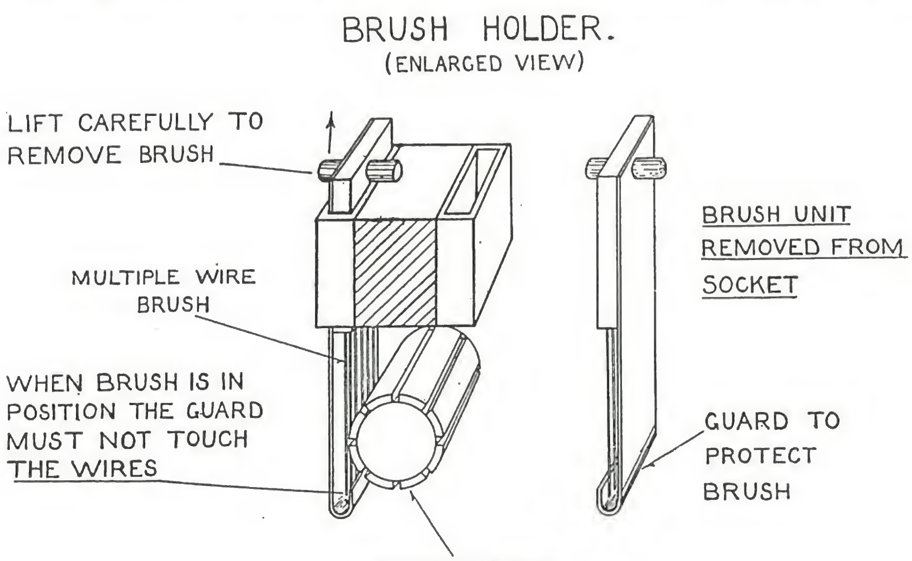


FIG. 55

(By courtesy of the Record Electrical Co., Ltd.)

generating sufficient current at an exceptionally high voltage to operate high torque and high resistance indicators. It employs a cobalt steel magnet, in the field of which revolves a multi-pole armature running on

ball-bearings, and it is enclosed in an aluminium case. A strong nose is fitted on the driving end, threaded to receive a British standard flexible drive, and the armature shaft is connected to the drive by a floating coupling, so that no strains are transmitted to the armature (Fig. 54).

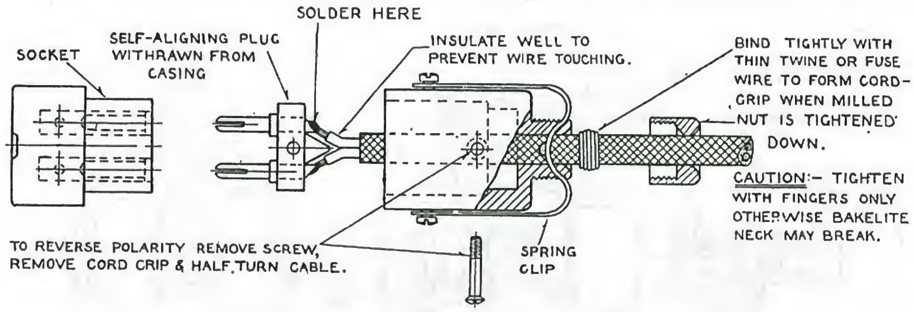


Fig. 56

(*By courtesy of the Record Electrical Co., Ltd.*)

Fig. 57. Cirscale Type

Patent

Alternative Ranges: 1,400–2,800 r.p.m.

" " 1,600–3,200 r.p.m.

(or others as required)

Weight 1¼ lb. Actual size 3¾ in. × 3¾ in. × 3¼ in. deep.

(*By courtesy of the Record Electrical Co., Ltd.*)

The armature is standardized to give 30 volts at 3,000 r.p.m. If the flexible shaft speed is quarter engine speed, i.e. 750 r.p.m., then four-to-one gear wheels are fitted. If the flexible shaft is running at any other speed. appropriate gear wheels are fitted instead. The gear-box is built into the generator and so constructed that the wheels can be changed at any time with very little trouble. So can the form of the nose, should it be desired to adapt the equipment for other than British service engines.

The commutator and brush gear are completely enclosed, but can be inspected by removing the moulded bakelite end cover. The brushes are of gold alloy, protected in a safety holder. Provision has been made for their renewal should occasion arise. To renew a brush all that is necessary is to slide out the old and insert the new (Fig. 55). It is advisable, after the generator has been run for about 500 hours, to remove the brushes and carefully clean away any deposits, particularly from the commutator slots. A toothbrush is very handy for this purpose. If the brushes are worn they should be replaced by spares. No lubrication whatever should be put on the commutator and on no account on the generator bearings and gear-box, which are packed with special grease to withstand extreme hot and cold temperatures.

The electrical connections between the generator and indicator are made by means of specially designed plugs and sockets (Fig. 56). The socket is fixed to the generator, and the plug is held in position by a spring clip, so that it is impossible for it to vibrate loose and become disconnected. Both the socket and plug pins are encased, preventing a short-circuit should they come in contact with any metal parts. The plug is provided with a cord grip. Every plug is interchangeable, both on the generator and indicator ends, the indicators all being fitted with a similar socket. They are also non-reversible, so that when the connections are once correctly made in respect to polarity, the indicator cannot be incorrectly connected. Provision, however, is made for easily correcting any error in polarity which may be made during installation without unsoldering connections; every internal electrical connection is soldered, and the plug connections must also be soldered to ensure reliability.

A desirable form of indicator is the Cirscale pattern, consisting of a patented moving coil voltmeter of unique construction, giving an angular deflection of the pointer of 300 degrees without gearing (Fig. 57). It is fitted in an aluminium case, and efficiently screened to bring compass interference within the prescribed limits.

The Edgewise type of indicator has been designed for compactness, and for readily comparing the speeds of the engines, as similar speeds are in line on the respective dials. It is constructed on the unit principle, each voltmeter being a complete and separate unit, and two or more are screwed side by side on a base to make twin, triple, or other multi-engine indicator (Fig. 58). Each separate unit is complete with its socket and plug as before described, and each is so effectually shielded that the removal of one indicator or any interchange in its position does not affect the readings of the others in the slightest degree. Moreover, a triple edgewise indicator, when placed at a distance of 10 in. from a sensitive compass, will not deflect it more than 2°. This deflection is not varied by engine speed, and can be readily and permanently adjusted on the compass corrector magnets. The dials have a black surface, with engraved scale and figures filled in white, or with scale marks and figures luminized.

The indicators are mounted on the dashboard so that the face is flush with the front of the dashboard. This means that the main body of the indicator projects behind the dashboard, and as the instruments are

somewhat heavy it is very advisable that some means of supporting the rear end of the instrument should be provided. On some aircraft it has been found that the vibration set up by the engine(s) has an effect on the indicators, causing the readings to be unsteady at certain engine speeds. In such cases it is advisable to introduce rubber "buffers" at the points of attachment of the instruments, so that the vibration effects may be damped out.

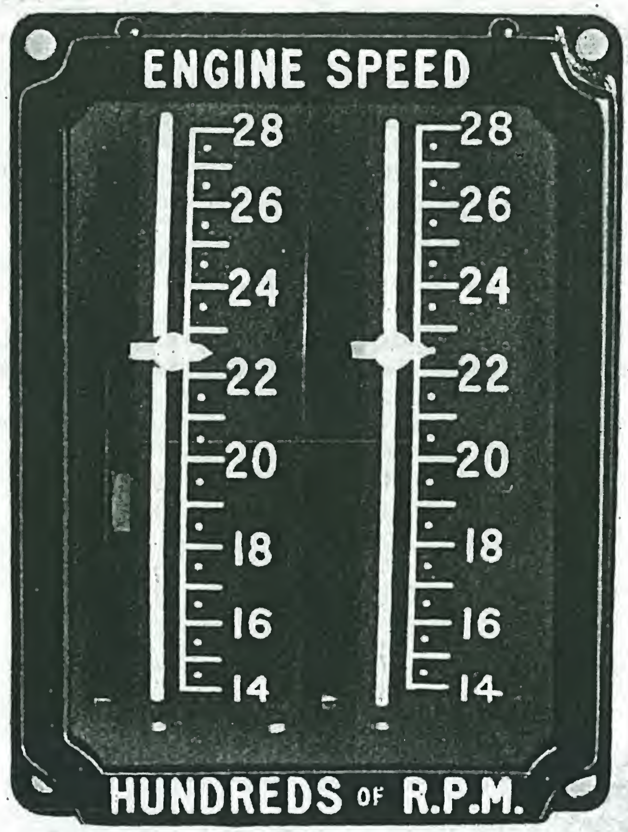


FIG. 58. TWIN EDGEWISE TYPE
Weight 4 lb.
(By courtesy of the Record Electrical Co., Ltd.)

Each generator is standardized to supply current to dual indicators. When one indicator only is employed a resistance must be put in the circuit equal to the load of another indicator; this resistance will be found at the end of the generator (see Fig. 53, "Substitutional Resistance"). To put this resistance in or out of circuit, turn the milled edge right to "I" when using one indicator and left to "II" when using two indicators.

Generators and indicators being screened are not affected by the presence of any mass of iron near them. Aluminium parts used in their construction are anodized and iron parts cadmium-plated, afterwards heavily coated with a cellulose enamel, thus affording protection against climatic conditions.

CHAPTER V

MAGNETOS

A HIGH-TENSION magneto, as used for producing the high-tension current in the ignition circuit of an engine, is really two separate pieces of mechanism in one, viz., a dynamo and a transformer, the latter operating to produce a high-tension current by means of the low-tension current supplied to it by the former.

The dynamo portion of the machine is, in many cases, constructed on quite orthodox lines, and consists simply of a permanent magnet, in the field of which revolves a plain two-pole armature carrying a single winding of relatively heavy gauge wire, called the primary winding.

In magnetos used for ignition purposes on engines with upwards of six cylinders this construction is somewhat modified, as will be explained later, in order to enable the machine to run at a lower speed than would otherwise be necessary, but the principle of operation is the same.

To return to the simple case already referred to, the dynamo is not fitted with a commutator, but with the equivalent of a single slip-ring, and this takes the form of an insulated contact screw which rotates with the armature. One end of the primary winding is permanently connected to "earth," or the metal body of the armature, the other end being connected to the insulated contact screw. This screw is affixed to a plate on the end of the armature, and this plate also carries a pivoted arm provided with another contact screw which is in contact with "earth." The two contact screws are normally kept in close contact by means of a spring. We thus see that under normal circumstances the primary winding of the armature is short-circuited, as one end is permanently attached to "earth," and the other end is connected to earth through the connection at the two contact screws, one of which—the fixed one—is insulated, and the other permanently earthed. If the machine is rotated in this condition, therefore, we shall generate an alternating current in the closed primary winding. As the magnetic field has only one north and one south pole, and as the armature has only a plain winding, each "arm," or "side," of the armature winding cuts the magnetic lines of force at a pole-face twice in each revolution, i.e. once at the north pole and once at the south pole. It therefore follows that the E.M.F. generated in the armature winding reaches a maximum in each direction once per revolution, or, in other words, we obtain a maximum voltage—usually about 10 to 16 volts—twice in each revolution of the armature. A graph of the changes in this E.M.F. would show the voltage commencing from zero, rising by a gentle curve to a maximum, then descending to zero, and rising again to a maximum on the opposite side of the zero line, again to return to the zero position.

So much for the dynamo side of the machine, and now to consider the transformer, or step-up side. A transformer is yet another device which operates by reason of the cutting of lines of force by a conductor. When lines of magnetic force are cut by a conductor an E.M.F. is produced in that conductor. With a magnetic field of given strength, the value of the E.M.F. produced in a conductor depends on the number of lines of force cut in a given time, and if a number of such conductors are connected together in series, then the total resulting E.M.F. is the sum of the E.M.F.'s produced in the separate conductors. Thus a much greater E.M.F. can be

produced from a large number of conductors connected in series than can be produced from a small number of conductors operating under con-

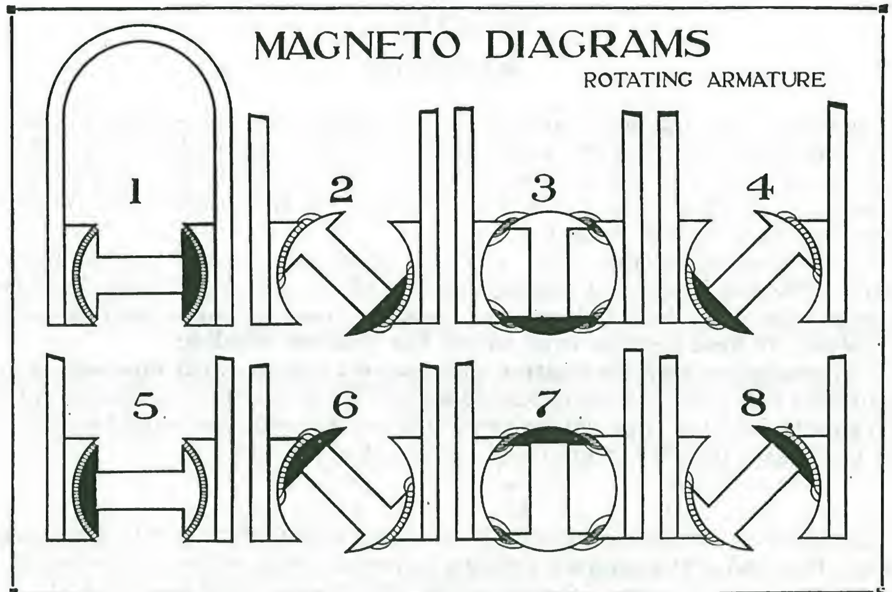


FIG. 59

(Royal Air Force Official—Crown Copyright Reserved)

ditions which are otherwise similar. Again, the important point to remember is that it is the cutting of the lines of force which produces the E.M.F.,

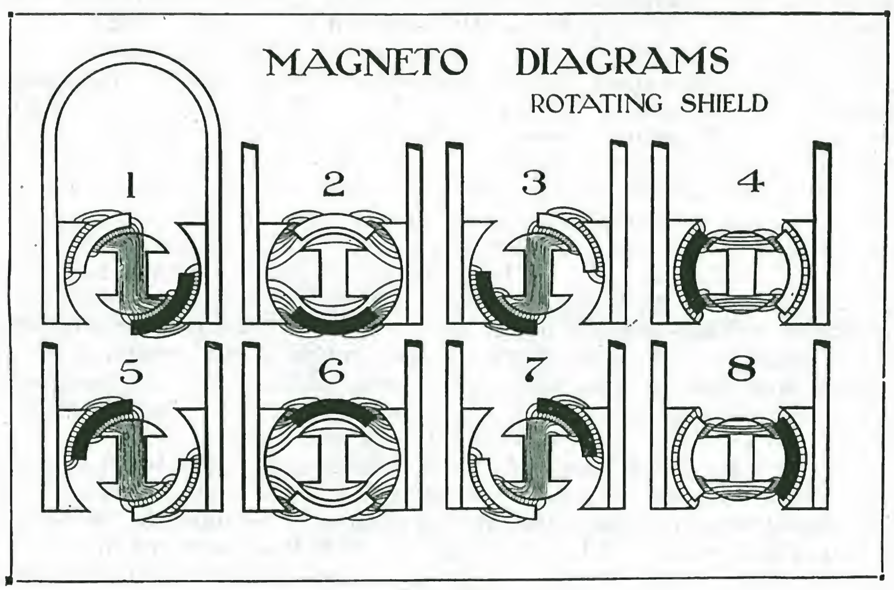


FIG. 60

(Royal Air Force Official—Crown Copyright Reserved)

and provided this can be established, it does not matter which moves—the conductor, or the magnetic field. Precisely the same result can be

obtained without either the conductors or the magnetic field moving, simply by causing the strength of the magnetic field to vary. (Fig. 60.) It is this latter condition which obtains in the transformer contained in a magneto.

It has been shown that by rotating the armature of the dynamo we have produced in its primary winding an alternating E.M.F. This armature winding is therefore in itself an electro-magnet, by reason of the current circulating in the conductors. The strength of this electro-magnet is largely increased by reason of the fact that the conductors are wound upon an iron core. The armature of the magneto, in addition to carrying the primary winding referred to, which consists of relatively few turns, also carries an entirely separate winding, consisting of a very large number of turns of fine gauge wire, which is called the secondary winding. One end of this secondary winding is permanently connected to "earth" and the other end is brought out to a highly insulated slip-ring, mounted on the armature shaft at the end remote from the two contact screws already referred to.

When the armature is revolving there is an alternating E.M.F. produced in the primary winding, and this alternating E.M.F. causes the winding, with its iron core, to produce an alternating magnetic field. The lines of force of this field—not the lines of force of the relatively weak fixed permanent field—are cutting the conductors of the secondary winding already referred to, and producing in it another E.M.F. of higher voltage than that produced in the comparatively small number of turns of the primary winding. But because the E.M.F. in the primary winding is rising and falling at a comparatively slow speed, the resulting lines of force are cutting the conductors of the secondary winding at the same comparatively low speed.

Although the E.M.F. thus produced in the secondary winding is higher than the E.M.F. in the primary winding, yet it is still not high enough to be able to produce a spark at the points of a sparking plug, and it is necessary to raise it considerably before it can be of any use for ignition purposes. This result is attained by causing the conductors of the secondary winding to be cut by the lines of force at a very much greater speed, and this speeding up is attained without increasing the speed of rotattion of the armature, simply by breaking the primary circuit at the moment of maximum E.M.F. When the primary circuit is broken at the moment of the maximum E.M.F. there is a sudden collapse of the magnetic field, just at the moment of its maximum intensity. The lines of force, therefore, collapse very suddenly, and in doing so they cut the conductors of the secondary winding at very high speed, and produce in it a momentary E.M.F. of a very high value, and this is used to produce the spark at the sparking plug. The sudden breaking of the primary circuit is accomplished by opening the two contact screws already referred to. These screws, one of which is fixed, and one mounted, on a pivoted arm, are carried by a plate mounted on one end of the armature shaft. This plate revolves within a fixed annular ring, which is provided with two slight excrescences to form cams. As the armature is revolved, the end of the pivoted arm carrying one contact screw is struck by these cams, and the screw at its other end is thereby forced out of contact with the fixed contact screw, and the primary circuit is broken.

In order that the E.M.F. in the primary winding shall reach as high a value as possible, it is essential that no unnecessary resistance be included in the circuit, and the two contact screws are therefore tipped with platinum or a special hard alloy of high conductivity which will withstand the hammering action to which it must be subjected under working conditions.

To avoid the destructive effects of sparking at these contact points, a condenser is incorporated in the magneto and is connected straight across the points.

The sparking at the points is the outward sign of the highly inductive quality of the circuit which is being broken, and it has already been pointed out (page 18) that inductance in a circuit produces an effect analogous to inertia of the current, i.e. the effect is to tend to maintain the flow of the original current after the instant of opening circuit. This effect would tend to slow up the breakdown of the magnetic field and thus reduce the strength of the secondary current, but the presence of a condenser across

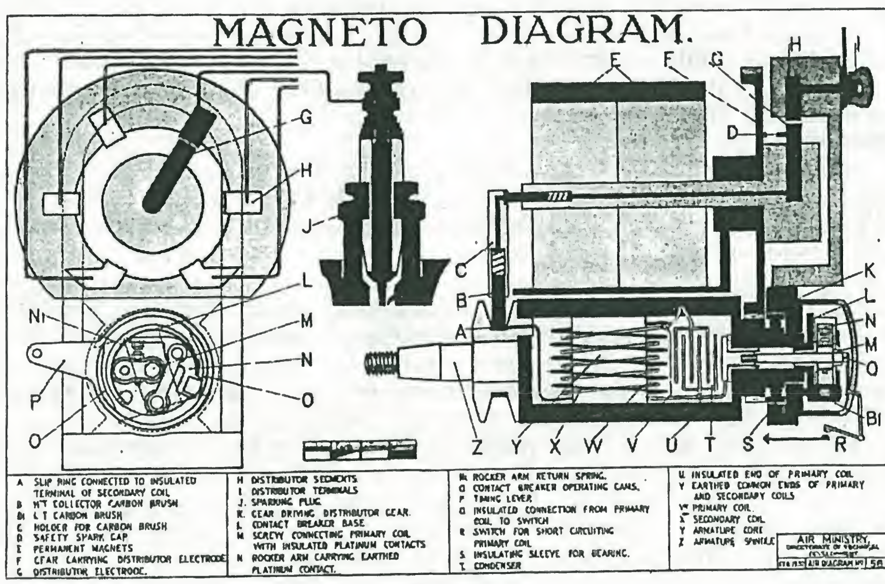


FIG. 61

(*Royal Air Force Official—Crown Copyright Reserved*)

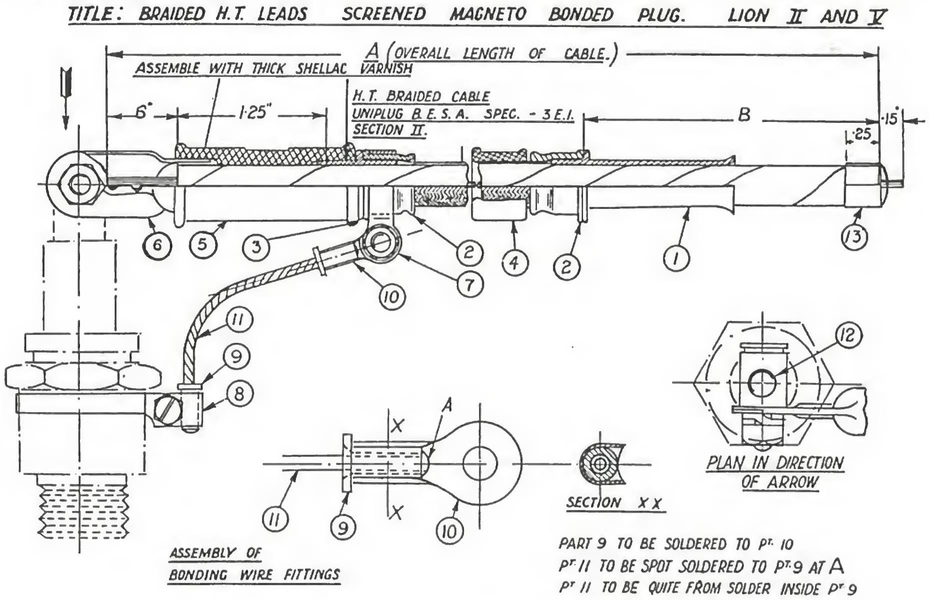
the contact points provides a reservoir into which the inductive current can flow quickly, and thereby not only is the destructive effect of sparking at the points avoided but a more rapid breakdown of the magnetic field is achieved.

Whilst the foregoing is the basis of design of all magnetos, and is that actually adopted in nearly all magnetos designed for use with engines having up to 4 or 6 cylinders, certain modifications in construction are adopted for magnetos designed for use with engines having a larger number of cylinders.

It has already been explained that magnetos such as that described above will produce two sparks per revolution of the armature. A single cylinder four-stroke engine requires one spark for each two revolutions of the crankshaft, and a four-cylinder engine will require four sparks for each two revolutions of the crankshaft, or two sparks per revolution. Thus, a magneto such as that described, if connected to a single cylinder engine, would revolve at one-quarter engine speed, and if connected to a four-cylinder engine, at crankshaft speed. When the number of cylinders is increased the number of sparks required per revolution of the engine is also increased, and these could be obtained by increasing the speed of the magneto in relation to that of the engine. But when we get

to a 12-cylinder engine, such a magneto would require to revolve at three times crankshaft speed, and thus might have to revolve at 6,000 to 9,000 r.p.m.

To construct an ordinary magneto to revolve at such high speeds is not a practicable proposition, as the result would be a heavy machine of inferior reliability. The problem is solved by introducing certain modifications into the design of the magneto, which result in obtaining four sparks per revolution of the armature instead of only two. It is



Nº	PART Nº		Nº OFF	Nº	PART Nº		Nº OFF
1	A.G.S.	1511	1	8	A.G.S.	1534	1
2	A.G.S.	1512	2	9	A.G.S.	1599	2
3	A.G.S.	1513	1	10	A.G.S.	1600	1
4	A.G.S.	1514	1	11	A.G.S.	1598	1
5	A.G.S.	1515	1	12	A.G.S	1535	1
6	A.G.S.	1516	1	13	A.G.S.	1518	1
7	A.G.S.	1537	1				

FIG. 62

(R.A.F. Official, Crown Copyright Reserved)

not necessary here to enter into details of such modifications, except to say that they consist of the duplication of the magnetic circuit, and this duplication again is achieved in different ways by different magneto manufacturers.

In such machines it is also customary to remove the primary and secondary windings from the revolving armature, and to introduce them into the stationary outer magnetic field. The strength of this field is varied by the revolving plain iron armature, resulting in the production of an alternating E.M.F. in the stationary primary winding, and the rupture of this E.M.F. in exactly the manner already described.

Having seen how the high E.M.F. necessary to effect ignition in an engine is produced, it remains to describe how the current is conveyed to each cylinder in turn. To effect this the magneto is fitted with a piece of mechanism termed a distributor. Although the distributor is normally

incorporated in the magneto, there is no particular reason why this should be so, except ordinary convenience.

The distributor consists of a revolving brush which rotates within a

SKETCH SHOWING L.T. CABLE CONNECTIONS. MAGNETO CUT-OUT SWITCH FOR TWIN ENGINE (SCREENED CABLES)

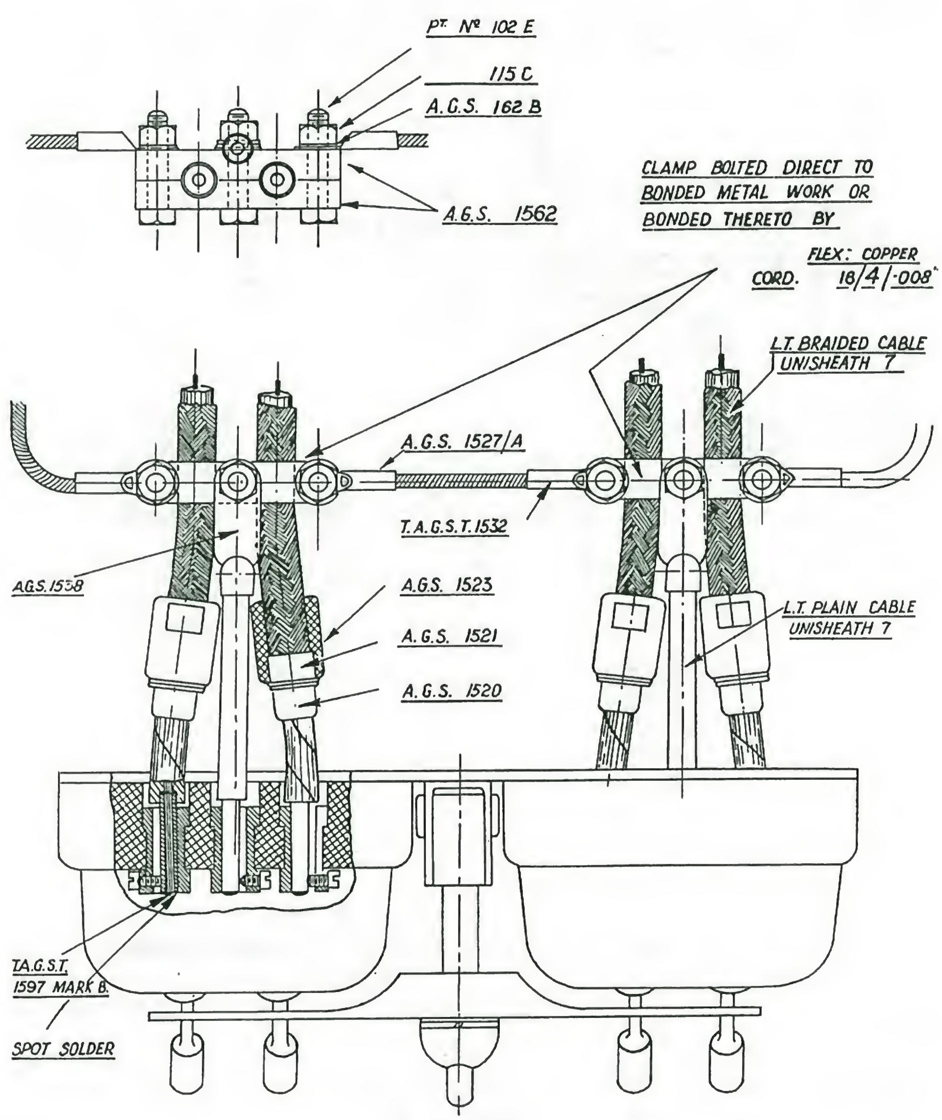


FIG. 63

(R.A.F. Official, Crown Copyright Reserved)

ring of insulating material containing a number of fixed conducting points of metal. These points are equal in number to the number of cylinders in the engine, and are equally spaced around the periphery of the ring of insulating material. The rotating brush is also of insulating material, but has moulded into it a core of conducting material which is in permanent connection with the unearthed, or insulated, end of the secondary winding.

The brush may be provided at its outer extremity with a spring loaded carbon brush, which makes contact as it revolves with each of the fixed metal points in the outer ring in turn. It is more usual, however, in modern magnetos, to dispense with the carbon brush and to leave a small fixed air gap between the fixed contacts and the revolving metallic brush.

Since each cylinder in the engine is required to fire once in two revolutions, it follows that the distributor brush must make one revolution to every two revolutions of the engine. The distributor brush is driven by gearing from the armature shaft, the ratio of the gearing varying with the number of cylinders in the engine, and the ratio of the armature speed to the engine speed. A highly-insulated lead is taken from each of the fixed contact points of the distributor to each of the sparking plugs in the engine. If wireless equipment is installed on the aeroplane it is necessary to **screen the magneto** and ignition leads in order to minimize interference with wireless reception. The sparks produced at the sparking plugs and within the distributor will set up violent oscillations in the aether, and the high-tension leads to the plugs are excellent aerials for propagating the aether disturbances, which will be picked up by the aerial of the wireless receiving installation, and will produce loud crackling noises in the telephones, sufficient to drown all but the very loudest signals. Screening the magneto is accomplished by totally enclosing the whole of it, especially the distributor, in an earthed metal case. The ignition leads are screened by braiding them externally with fine wires, which cover every portion of the insulation of the wire, and are also earthed. The braiding over the leads should go right up to, and be connected with, the metal case over the distributor. At the other end, it should be continued to within 1½ in. of the sparking plug terminal, and also be earthed at that end, and at all intermediate clamping points. (See also pages 176–180.)

There is a special type of shrouded sparking plug on the market which incorporates an insulated external metal shroud over the whole plug. This shroud is in contact with the metal braiding over the cable, and is also in direct contact with "earth." It is also very desirable to use metal-braided cable from the low-tension switch to the terminal connector at the contact-breaker. Where a metal-braided cable is used for this purpose, it is permissible to utilize the external metal braiding as an earth connection between one side of the switch in the cockpit and the metal body of the engine. It must not be overlooked that a length of metal-braided cable is, in effect, an electrical condenser, the external braiding forming one plate, and the internal conductor the other plate. The longer the length of such cable, therefore, the greater is its electrical capacity. When metal-braided high-tension leads were first introduced it was quickly found that they were liable to interfere with the satisfactory functioning of the magneto, and this was immediately traced to the inability of the magneto to supply sufficient energy to charge up the capacity of the leads, and at the same time have sufficient energy in reserve to produce a spark at the sparking plug. The trouble was cured by increasing the electrical output of the magneto, and there is little cause for complaint on this score, so far as modern magnetos are concerned.

Ignition systems utilizing high-tension cables with external metal braiding, however, require special protection and care against the effect of damp weather, if difficulty is to be avoided in connection with engine starting. The faintest trace of dampness on the outside of the cable, between the high-tension terminal of the sparking plug and the nearest point of the external braiding—which, of course, is earthed—is often sufficient to render engine starting extremely difficult, if not impossible. On engines provided with mechanical or some other form of engine starting gear

capable of turning the crankshaft over at a relatively fast speed, the effects will not be so marked, and the use of shrouded plugs will also tend to minimize the trouble which may otherwise be expected from this cause.

Magnetos for aircraft engines are divided into two classes: magnetos for light aircraft—generally of 4 to 7 cylinders and magnetos for heavier aircraft, from 9 to 14 cylinders, and upwards.

(A) Light Aircraft Magnetos

Magnetos for light aero engines are generally of the type where the armature rotates and produces two sparks for every revolution of the armature.

So far as possible, the magneto is built up of easily accessible components, or sub-assemblies—

Housing. This is die-cast aluminium with the armature poles cast integral with it, as is also the distributor endplate, the bearing at the driving end also being located in the same casting.

Armature. This consists of core, winding, condenser, and two endplates, one being integral with the driving spindle and carrying the ball-bearing from the driving end, the other forming a container for the condenser and carrying the bearing at the contact-breaker end of the magneto. The armature is of the standard "H" pattern with malleable cast-iron cheeks on a laminated core. This armature is wound with a primary winding of approximately 200 turns of ·7 mm. H.C.C. enamelled wire and has a secondary winding of 8,000 to 9,000 turns of ·0032 in. H.C.C. enamelled wire. The end of the primary and the beginning of the secondary are joined together and the two ends of the primary are brought out at the condenser end of the armature and are soldered direct to the condenser. The insulated end of the secondary is brought out at the top of the winding and enters a slip-ring which is pressed on to the driving spindle. The condenser is so fixed in its endplate that one side is earthed and the other end comes out to a boss which is insulated and allows for connection to be made through the endplate to the contact-breaker.

Contact-breaker. The contact-breaker revolves with the armature and is spigotted into the condenser endplate. The screw which fastens the contact-breaker assembly to the endplate also acts as a conductor for the L.T. current and clamps direct on to a brass block which is insulated from the base itself by means of fibre or some insulating material. This block also carries the adjustable contact. The contacts are usually of 25 per cent iridium and 75 per cent platinum. The lever which is controlled by a spring is the standard bell-cranked type and operates on a pivot formed integral with the base but insulated from the lever itself. The reason for this insulation is to prevent any current passing through the pivot and causing pitting and sluggish operation of the lever.

Between the contact-breaker base and the armature when assembled into the housing of the magneto, is an endplate which carries the bearing at the contact-breaker end of the armature and spigots into the housing. On to this endplate spigots a cam which operates the contact-breaker lever. This cam is a steel ring, hardened, and having ground on it two lobes—or, in some cases, these lobes are affixed to the rings and not integral with it. As the contact-breaker operates, these lobes open and close the contacts at predetermined positions.

Distributor Slow-speed Wheel Assembly. For magnetos of more than two cylinders a distributor and distributor gear-wheel are used. The slow-speed wheel assembly is on ball-bearings in a little housing which spigots into the distributor endplate. Through the centre of these bearings passes a brush holder. The brush holder is connected to the slip-ring of the

armature by means of a small "L"-shaped collector moulding, fastened at the driving end of the housing.

Timing of the Magneto. The timing of the magneto is very important and holes are usually provided in the top of the housing to allow for the insertion of a timing gauge. The armature is rotated in the direction in which it is intended to operate and the tip of the pole on the armature is spaced 3 to 4 mm. from the tip of the pole in the housing. With the armature held in this position the cam is rotated in its cover tube until the contacts are just opening on the leading edge of the lobe. The cam when in this position is fitted to the cam-cover tube which itself is fitted into the contact-breaker endplate by means of a screw. For magnetos arranged for variable timing, a slot is provided and for fixed ignition machines a recess large enough for the head of the screw only is provided.

A moulded contact-breaker cover is usually provided which has a terminal and a spring inside which makes contact with the screw fixing the contact-breaker assembly to the armature; thus, the lobe connected to this terminal provides a ready means of earthing the magneto when necessary.

These magnetos being arranged for a varying number of cylinders are run at varying speeds in relation to the engine, viz.—

2-cylinder	magnetos	run at	$\frac{1}{2}$	engine	speed
4-cylinder	,,	,,		engine	speed
5-cylinder	,,	,,	$1\frac{1}{4}$	engine	speed
6-cylinder	,,	,,	$1\frac{1}{2}$	,,	,,
7-cylinder	,,	,,	$1\frac{3}{4}$	,,	,,

The 7-cylinder magnetos are strictly limited in their application, since it is inadvisable to run them above 5,000 r.p.m. continuously, and are therefore only applicable to relatively low speed 7-cylinder engines.

There is yet another application of the rotating armature magneto and that is where the magneto is used purely as a generator with a separate distributor-head on the engine; in this case, one terminal only is provided for distribution, both sparks passing through this terminal to the centre terminal of the distributor-head, whence, passing through the brush holder, it is distributed in the normal manner to each cylinder. This arrangement provides a very light ignition system and is preferable in some engine installations to a magneto and distributor in one unit.

Magnetos for Gipsy I Engines. One A.G.4-2 left-hand rotation, base-mounted magneto, bare shaft extension; height of armature centre, 38 mm. One A.G.4-2 right-hand rotation, base-mounted magneto, with type A Impulse starter and half Simms coupling; height of armature, 38 mm.

Magnetos for Gipsy II Engines (or as alternative on Gipsy I engines). One A.G.4-4 left-hand rotation, base-mounted magneto, bare shaft extension; height of armature, 38 mm. One A.G.4-4 right-hand rotation, base-mounted magneto, with type L.-2B. impulse starter and half Simms coupling, height of armature, 38 mm.

Magnetos for Gipsy III Engines. One A.G.4-4 left-hand rotation, base-mounted magneto, bare shaft extension; height of armature centre, 38 mm. One A.G.4-4 right-hand rotation, base-mounted magneto, with type L.-2B. impulse starter and half Simms coupling; height of armature centre, 38 mm., arranged for running in an inverted position.

Type A.G.4 Magnetos

These magnetos are of the standard rotating armature type with a strong magnetic field which remains constant over an extended period.

The magnetos are base-mounted and are supplied with height of centres of spindle above the base of 38 mm.

Housing. The housing is die cast, with the distributor endplate and driving endplate integral parts of it, thus making an exceedingly rigid mechanical structure.

Windings. The primary and secondary windings are wound on the usual "H" type armature. The beginning of the primary winding is connected to the core, whilst the end is joined to the insulated side of the condenser and to the beginning of the secondary winding. The other end of the condenser is connected to the core. The insulated side of the condenser is connected to the insulated platinum contact of the contact-breaker, and the insulated end of the secondary is connected to the brass insert in the slip-ring.

Contact-breaker. The contact-breaker is of the usual design, i.e. a brass base on which is mounted an insulated contact block carrying an adjustable contact, the other contact being carried on a bell crank lever. The timing lever, by means of which the moment of ignition is varied, may be moved through an angle of 25 degrees.

Safety Spark Gap. To prevent the armature being damaged in the event of an interruption of the external high-tension circuit, safety gaps are provided, and in each case they are fitted on the brush holder and operate between the distributor brush and the slow-speed wheel.

Current Distribution. The distributor brush connected to the end of the secondary winding is mounted on the gear-wheel and rotates at half armature speed.

The earlier types of A.G.4 magnetos were fitted with a bronze distributor wheel meshing with a Textolite armature wheel. In the later types, the distributor wheel is made of Textolite and meshes with a steel armature wheel. Where replacements are necessary for the older type machine, the armature wheel can be replaced by a steel one and still mesh with the bronze distributor wheel, but the bronze distributor wheel cannot be replaced for a Textolite wheel for meshing with a Textolite full-speed wheel; both must be changed to the later combination.

Type A.G.4-2 magnetos are fitted with a plain journal bearing for the slow-speed wheel, and the oiling instructions given under "Maintenance in Service" should be strictly followed.

Type A.G.4-4 magnetos are fitted with a ball-bearing for the slow-speed wheel and no means of lubrication is provided.

Direction of Rotation and Relative Speed. Each magneto is arranged for one direction of rotation only and bears an arrow stamped in a conspicuous position, which indicates the direction for which the particular machine is designed. The driving speed, for all A.G.4 types, is crankshaft speed.

Installation. Set the engine to the correct firing position of No. 1 cylinder and turn the magneto armature in the direction indicated by the arrow until the distributing brush approaches No. 1 segment of the distributor. The contact-breaker should be in the fully advanced position and the contacts just separating (by not more than ·0015 in.). The magneto driving wheel or coupling can then be engaged with the driving wheel or coupling on the engine drive and the magneto fastened in position.

Cutting Out the Magneto. The magneto may either be cut out of action by short-circuiting the primary winding—and this is easily done by connecting the terminal on the contact-breaker cover through a switch to the frame—or earthed. When the switch is closed the magneto will be inoperative.

LUBRICATION

(*a*) *A.G.*4-2 *Magneto* (*Gipsy I*). The rotating armature of the magneto is fitted with two ball-bearings which are packed with Price's High Melting Point Grease before the magneto leaves the works.

The only part requiring lubrication is the distributor gear-wheel bearing, and eight (8) drops of light oil poured into the oil well at the distributor end of the magneto, every 25 hr. running, is sufficient.

Should the magneto stand for two weeks or more or the oil wick become dry, then the distributor end cup should be filled with oil until the oil overflows through the drain-hole seen on the left when facing the distributor.

(*b*) *A.G.*4-4 *Magneto* (*Gipsy II and III*)—or as alternative on Gipsy I.

All bearings in this magneto, fitted to both armature and slow-speed wheel, are of the ball-bearing type and are packed with Price's High Melting Point Grease before the magneto leaves the works. No provision is made for oiling the magneto at all, and it should not be necessary to disturb the bearings for filling with grease until a general overhaul of the engine, at the end of 450 hr. flying, is made.

NOTE. The platinum points of the contact-breaker must be kept absolutely free from oil. This is of the utmost importance, because any oil on the contacts will become oxidized and prevent good electrical contact between the platinum points when closed. The current from the magneto may be reduced considerably on this account.

Distributor and Brush Holder. Remove the distributor and clean the inside of it with a cloth moistened with petrol. Any dust or foreign matter that may accumulate inside the distributor is liable to cause leakage, the symptoms of which are misfiring or poor starting. In a similar manner wipe the surface of the brush holder.

Slip-ring and Collector Brush Holder. Remove the aluminium dust cover at the driving end of the magneto and take out the collector brush holder, which is secured to the top of the main housing by two screws, and with a cloth moistened with petrol wipe off any dust from the cone. Do not unnecessarily remove the carbon brush from the collector moulding.

Clean the flanges of the slip-ring in a similar manner. This can be done by lightly pressing one corner of the cloth between the slip-ring flanges and slowly turning the engine crankshaft, making sure that the magnetos are switched off.

Contact-breaker. The contact-breaker is readily accessible by removing the cover and can be withdrawn from the magneto after unscrewing the centre fixing screw.

Examine the contacts and if these are dirty the surface of each contact should be cleaned with a piece of very fine emery cloth or paper, care being taken to remove any emery dust which may have accumulated.

Examine the bell-crank lever bearing bush and if dry, smear with a little light oil. After re-fitting the lever on the bush, it is important that any excessive oil should be wiped off.

Refit the contact-breaker, taking care to locate the key on the contact-breaker base in the keyway of the armature spindle. With the feeler gauge on the spanner supplied with the magneto, check the contact gaps when the heel is on the high part of the cam; this gap should be 0·012 in. and if necessary should be carefully adjusted to this dimension by the aid of the feeler gauge and spanner. Do not adjust the contact gaps unnecessarily.

Adjustment and Location of Faults. If the engine is firing irregularly, though some portion of the ignition system is frequently at fault, the

magneto is not always the cause of the trouble. The investigator should, in the first place, satisfy himself that the fault does not lie in the plugs, the sparking gaps of which should be about 0·4 mm. (= ·016″).

Irregular firing might result from defective operation of the contact-breaker. To determine whether this is the case, the contact-breaker cover should be removed with a view to observing if the contact-breaker fixing screw is securely tightened.

Special attention should also be given to the platinum screws which should be securely locked in position. The platinum points should be carefully examined, and, if necessary, cleaned with very fine emery cloth. When the armature is revolved the maximum contact gap should be set to the feeler gauge provided on the contact-breaker spanner. This gap should, from time to time, be checked and, if necessary, the long contact screw should be adjusted.

Examine and, if necessary, clean the high-tension mouldings as instructed.

If sparking persistently occurs at the safety gap of the magneto, it is an indication that there is a break in the external high-tension circuit. If the engine stops firing altogether, it is probably due to the conductor from the low-tension earthing terminal of the magneto coming in contact with the frame, thus rendering the magneto inoperative.

If the investigation indicated above does not reveal the cause of the faulty ignition, the magneto should be returned to the makers.

Dismantling the Magneto. Total dismantling of the magneto should be rarely necessary, but instructions are given below in case this should be required.

In the ordinary way, the only attention which need be given to the magneto is to examine the contact-breaker, which is readily accessible, and may be removed and replaced without disturbing any other working part of the magneto.

In dismantling the magneto, the following procedure should be observed.

1. Remove the contact-breaker cover, cam ring, and distributor moulding.
2. Remove dust cover at the back of magnet, also the collector moulding underneath.
3. Remove earthing brush on left-hand side of housing, looking at the distributor end.
4. For A.G.4-2 magnetos, remove the slow-speed wheel oil-well and wick on right-hand side of housing, looking at distributor end.
5. Remove the contact-breaker endplate.
6. Remove the slow-speed bearing assembly.

(*a*) In the case of A.G.4-2 magnetos, this is accomplished by removing the locking ring, at the back of the bearing underneath the magnet, which is sprung into a groove in the spindle. It is possible to get at this locking ring by slightly moving the magnet on the pole shoes after having removed the magnet screws. A soft iron keeper passing under the base of the magneto must be fitted on the poles of the magnet before this is done.

(*b*) In the case of A.G.4-4 magnetos, the bearing assembly is dismantled by unscrewing the four screws fastening the bearing housing into the distributor endplate, and can be removed through a hole in the slow-speed wheel from the front of the magneto.

7. The armature may now be withdrawn from the housing, but in every case before this is done a keeper must be fitted to the magnet, or else it will be necessary to remagnetize the magnet on reassembly.

NOTE. When reassembling the magneto, great care should be taken

to ensure that the key on the contact-breaker base engages with the slot in the armature spindle.

Watford Types

The principle on which the Watford four-spark magneto is made is that of the pure inductor. The inductor consists of two cheeks which are assemblies of laminae mounted concentrically on a hollow spindle made of high tensile steel, the design of which makes a very light construction. The inductor runs in a tunnel on ball bearings. The bore of this tunnel presents six poles to the inductor, four of which are connected to the extremities of four permanent bar magnets and the other two form part

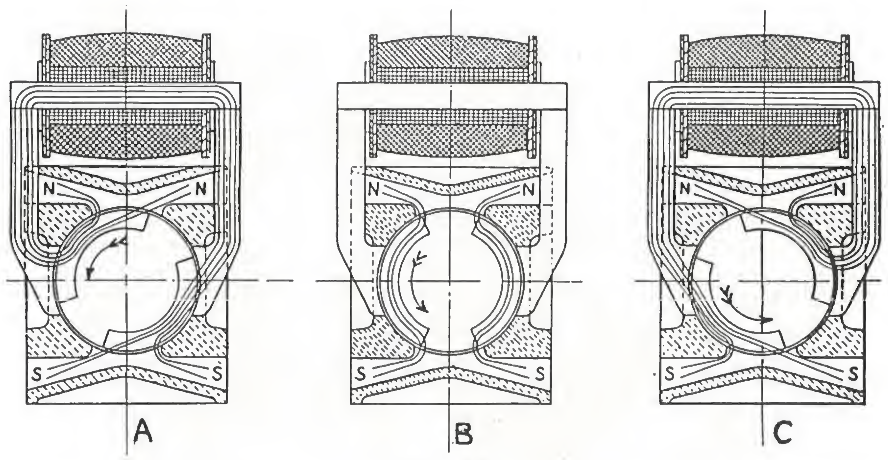


Fig. 64

of the armature core. The whole of the laminated pole shoes, which are made of a special high permeability steel, are cast in a casing of aluminium to ensure a solid construction, the pole shoes representing cylindrical faces to the inductor.

The action of this inductor principle will be easily understood with reference to the three diagrams showing the flux changes for different positions of the inductor through 90° movement.

Fig. 64A shows the flux direction from N. through the armature via the left-hand limb of the armature core.

Fig. 64B shows the rotor in a position giving zero flux, i.e. the flux is passing from one pole of the magnets to the other pole through the rotor.

Fig. 64C shows the flux direction from N. through the armature via the right-hand limb of the armature core.

As will be seen from the illustrations, the armature core is stationary.

The low-tension current can be traced on the diagram (Fig. 65), the lead being enclosed within the magneto and terminating at the insulated platinum screw carrier via the laminated bronze and steel connection *O*. The other end of the primary winding is earthed.

The outside lead of the secondary winding is connected to a fixed insulated terminal on the armature, and is transferred through the centre of the distributor rotor to the distributing electrode, thence jumping to the distributor segments, which are connected to the high-tension terminals in the distributor block. The distributor is fitted with a centre terminal to enable a hand-starter magneto to be used.

The condenser is mounted in a case of insulated material above the

armature. The condenser is connected in the usual manner, i.e. in parallel with the primary winding and the platinum contacts.

The entire magnetic flux system is laminated, and this in conjunction with the design of the tunnel and inductor is designed to give extremely active and intensely powerful magnetic flux alternations through the armature core. The speeds at which the magneto will run efficiently are much in excess of those obtainable by any other system. The magneto will function perfectly at 8,000 r.p.m., the number of sparks being 32,000 sparks per minute.

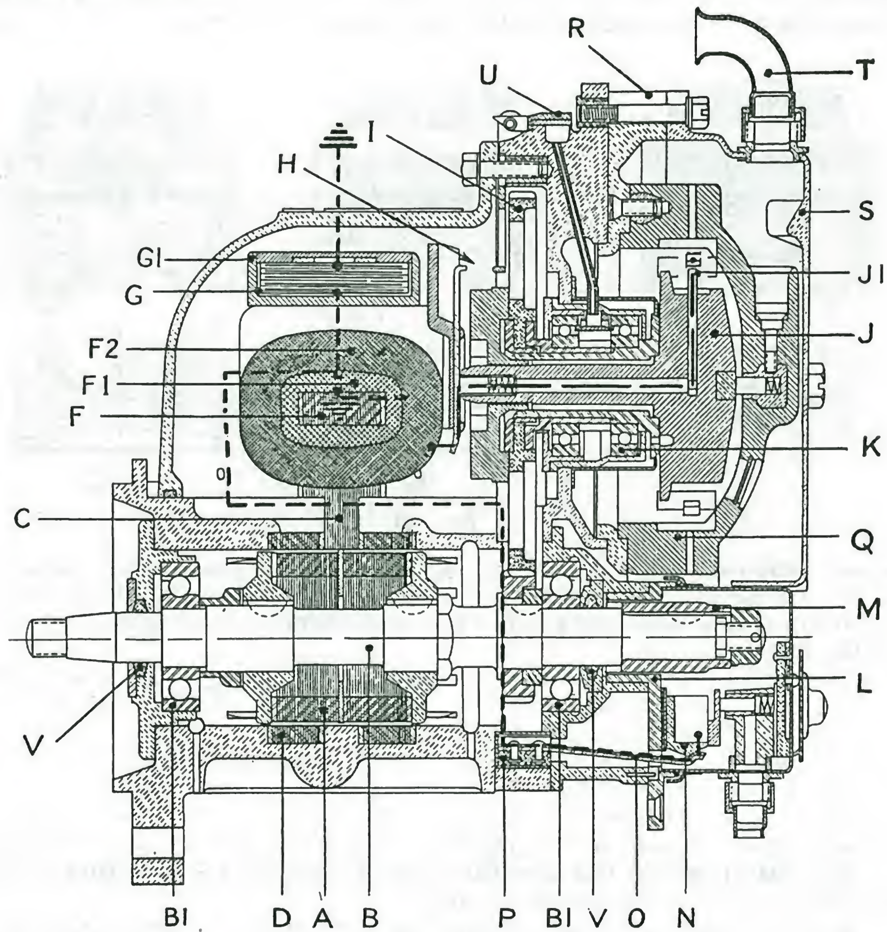


Fig. 65

A = Laminated inductor.
B = Hollow driving shaft.
*B*1 = Rotor bearings.
C = Armature pole shoes.
D = Magnet pole shoes.
E = Magnets.
F = Armature.
*F*1 = Primary winding.
*F*2 = Secondary winding.
G = Condenser.
*G*1 = Case of special insulating material for condenser.
H = Safety gap.
I = Distributor gear wheel.
J = Distributor rotor.
*J*1 = Distributor electrode.
*J*2 = Distributor terminal.
K = Distributor spindle ball bearings.
L = Stationary contact-breaker base.
M = Rotating cam.
N = Insulated platinum screw carrier.
O = Insulated low tension laminated connection to contact-breaker.
P = Insulated block for earth terminal wire
Q = Distributor block.
R = Aluminium mounting ring for distributor block.
S = Distributor block screen.
T = Hand starter terminal.
U = Common lubrication cap for all bearings.
V = Felt packing glands.

The magneto is fully screened to prevent interference to wireless apparatus.

The usual voltage under fully screened conditions, that is with 6 ft. of braided cable on each lead, is 10,000 volts.

Scintilla Type

The Scintilla-type magneto employs a rotating permanent magnet, and the delicate parts, such as the coil and the contact-breaker with its contact points, are stationary. The four-pole permanent magnet 1 (Fig. 65B) rotating between the stationary pole shoes 2 produces in the core 3 a

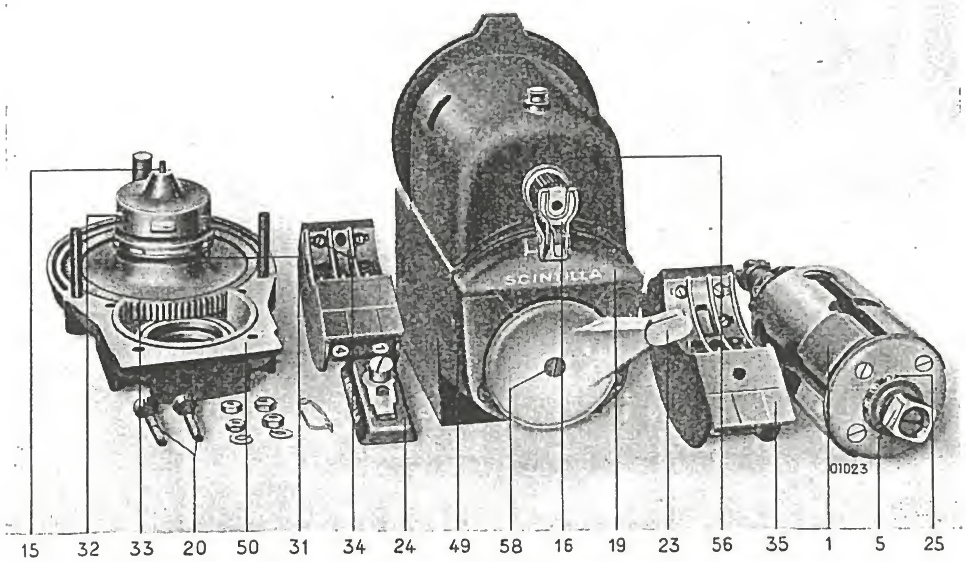


FIG. 65A. MAGNETO TYPE GN 8-D PARTIALLY DISMANTLED

strong alternating magnetic field. This magnetic field generates an alternating low-tension current in the primary winding 4, the latter being composed of a few turns of thick wire. When this current reaches its maximum value, the breaker cam 5 causes the breaker lever 7 to turn on its axle 6, thereby separating the contact points 10, thus leaving a gap between them. The cam is mounted on the back end shaft of the rotating magnet 1, its position being fixed in relation to the magnetic field. The short contact point 8 (Fig. 65C) is connected to the motor frame through the breaker lever 7 and the main spring 9, whereas the long contact point 10 is fixed to the insulated support 11, and is kept in permanent contact with the primary winding 4 by means of brushes fitted to the primary connecting strip 22. Owing to the contact points 8 and 10 separating, the primary current is suddenly interrupted. The normal width of the gap must be 0·3–0·4 mm. In order that there may be four interruptions per revolution, corresponding to the four maximum values of the primary current, the cam is provided with four bosses. For the same reason the cam is provided with two bosses for a permanent magnet having two poles, and with eight for a magnet with eight poles. The advancing and retarding of the ignition are obtained by making the contact-breaker assembly

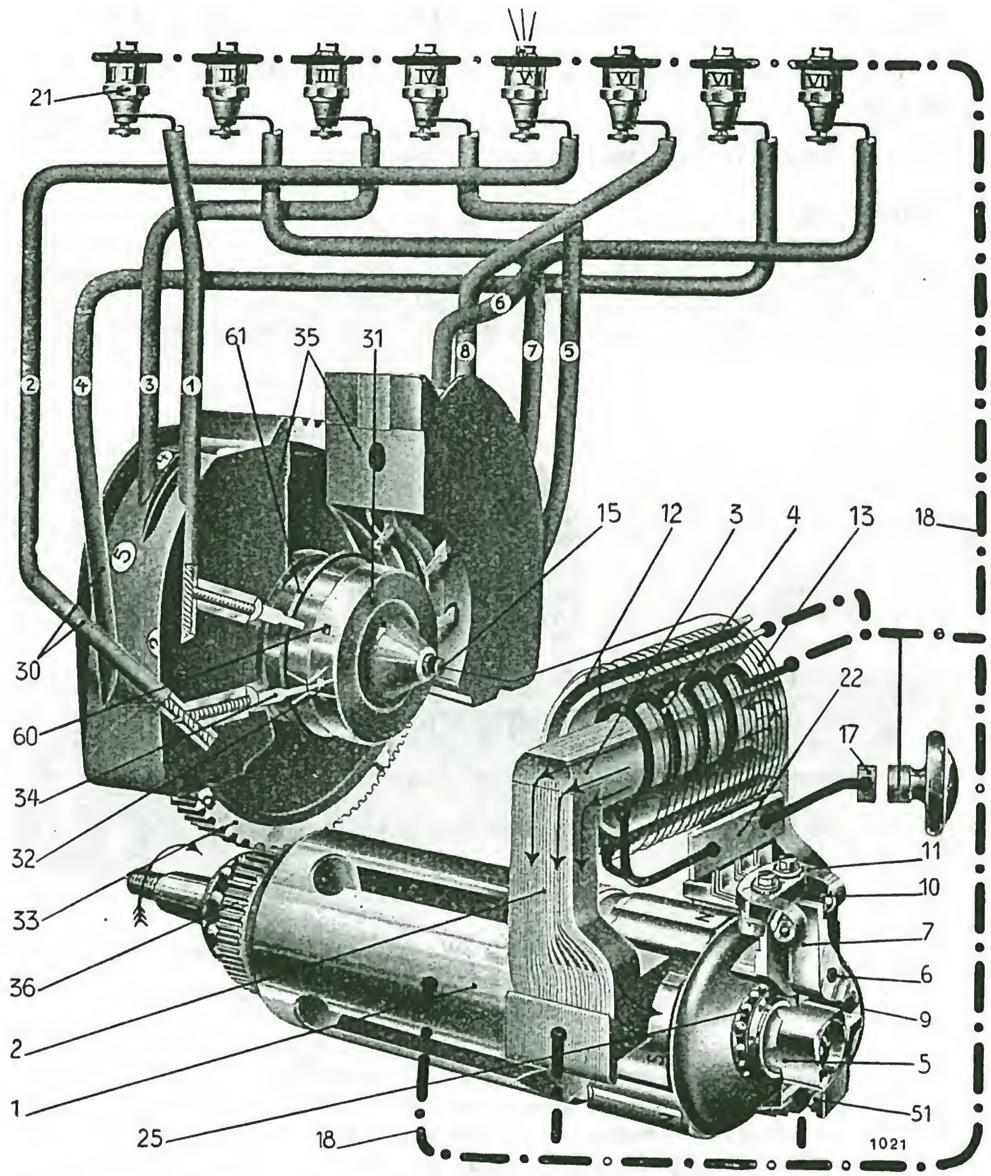


FIG. 65B. WORKING DIAGRAM OF THE MAGNETOS FOR 8-CYLINDER ENGINES

(An anti-clockwise rotating magneto is represented. To determine the direction of rotation the magneto should be viewed from the driving end.) Order of firing: 1, 7, 3, 5, 2, 8, 4, 6.

1. Rotating permanent magnet with laminated pole-pieces.
2. Stationary laminated pole shoes.
3. Laminated core of coil.
4. Primary winding.
5. Four-boss breaker cam.
6. Breaker lever axle.
7. Breaker lever.
9. Main spring for breaker lever.
10. Long contact point (insulated).
11. Insulated support.
12. Condenser.
13. Secondary winding.
15. High-tension carbon brush in distributor cylinder.
17. Insulated terminal of magneto switch.
18. Motor frame (ground).
19. Breaker cover.
20. Securing screw for front end plate.
21. Sparking plugs.
22. Primary connecting strip to fastening screw for ground wire.
23. End cover with advance lever.
24. Securing cover for distributor blocks.
25. Ball race (front end).
30. Ignition cables.
31. Distributor cylinder.
32. Segments in distributor cylinder carrying secondary current.
33. Large distributor gear.
34. Electrodes in distributor block.
35. Distributor blocks.
49. Magneto housing.
50. Front end plate.
51. Contact-breaker cage.
52. Contact-breaker locking ring.
53. Spring for contact-breaker end cover.
55. Coil.
56. Main cover.
58. Securing screw for contact-breaker end plate.
60. Segment in distributor cylinder carrying booster current.
61. Collector ring for booster current.

oscillate round the cam 5 by means of the timing lever 23 (Fig. 65A), the interruption of the primary circuit being thus advanced or retarded. The condenser 12, which is in parallel with the contact points 8 and 10, prevents abnormal sparking at these points when the interruption of the primary current takes place, thereby reducing their wear to a minimum and at the same time ensuring regular sparking. The sudden interruption of the primary current generates a high-tension current in the secondary winding 13, the latter being composed of a large number of turns of fine wire. One end of this secondary winding 13 is connected to the motor frame 18 through the primary winding 4, while the other end terminates at the central contact which forms part of the coil. The high-tension carbon brush 15 transmits the current successively to the sparking plugs 21 through the medium of the distributor. The high-tension carbon brush 15 of the distributor cylinder bears on the central contact of the coil, and is electrically connected to the two segments 32, which are simultaneously under pressure at every interruption. The distributor cylinder 31 is fixed on the large distributor gear 33 in a definite position relative to the contact-breaker. The segments 32 successively pass the electrodes 34 on the distributor blocks 35, thus transmitting the current through the ignition cables 30 to the sparking plugs. Referring to the diagram, electrode No. 1 is under pressure and a spark is produced at the plug of the first cylinder viewed from the front end.

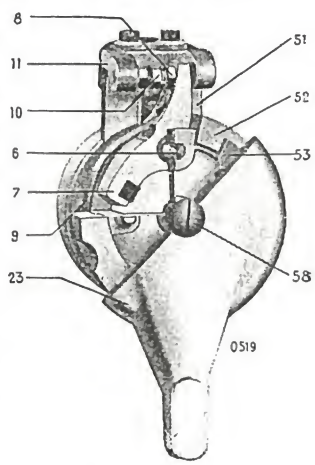


FIG. 65C.

SECTION THROUGH THE CONTACT-BREAKER OF A CLOCKWISE-ROTATING MAGNETO

The breaker cam has four bosses, consequently the magneto produces four sparks per revolution, and as these must succeed each other at equal intervals the bosses are displaced 90°. The distributor has to supply eight sparks, and must therefore rotate at half the speed of the driving spindle. On the other magnetos this alters according to the number of the cylinders—for example, on the twelve-cylinder magneto it is $\frac{1}{3}$. In order that the ignition may be cut out, the effect of the contact-breaker must be neutralized as follows (See Fig. 65B)—

The end of the primary winding 4 terminates, through the primary connecting strip 22, at the terminal to which is connected the primary cable. The latter is taken to the insulated terminal 17 of the magneto switch, the second terminal of the latter being connected to the motor frame 18. When the switch is closed, the primary winding is short-circuited and ignition ceases, due to the effect of the contact-breaker being neutralized. Aero engines are generally provided with a special ignition system for starting purposes, which is usually a small hand-driven magneto or battery ignition with separate coil and contact-breaker. In order to obtain the spark from the auxiliary starting device for the cylinder which is on the explosion stroke, the service magneto is fitted with a special distributor cylinder having four segments instead of the usual two. The starting segments are arranged to follow the service segments at a predetermined angle, and are connected electrically to the collector ring.

Scintilla magnetos described "D" (for example GN 12-D) are suitable for use in connection with an auxiliary starting device. The timing of these magnetos should be carried out in the following manner—

Turn the engine so that the piston of No. 1 cylinder comes towards the end of the compression stroke, and stop as soon as the point of maximum

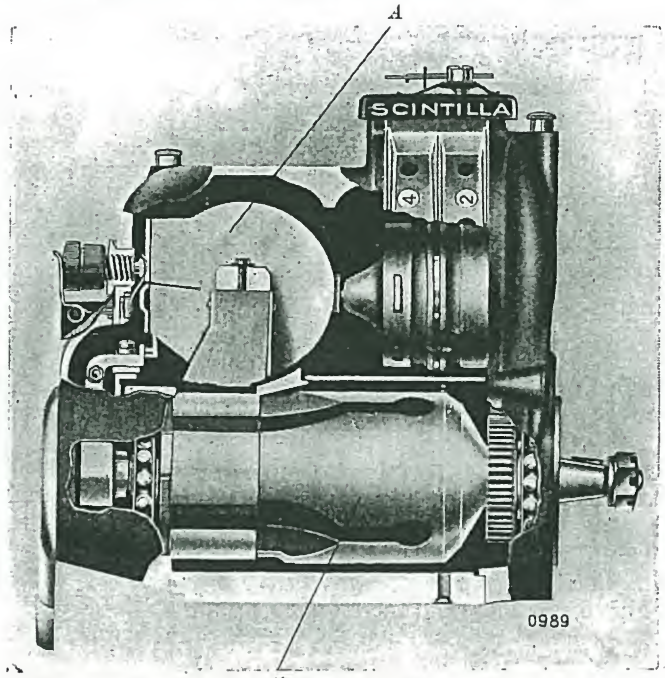


FIG. 65D. ROTATING MAGNET
Magneto type GN 8-D sectionalized
A Stationary coil carrying primary and secondary windings and condenser
B, Rotating Permanent Magnet

advance is reached—this is also the point where the engine develops its maximum power. Next, make the mark on the large distributor wheel (visible when taking off left-hand distributor block) correspond to the mark on the front end plate. At this moment the contact points open when the advance lever is in the advanced position. On magnetos with fixed ignition the contact-breaker is always in the advanced position. For the above-mentioned operation it is assumed that the driving couplings are already engaged, but that one of them is still loose on its spindle, unless an adjustable type coupling is fitted. When the timing is completed, the couplings should be firmly secured on their spindles. If the magneto has variable ignition, the advance lever is to be fixed in the most suitable of the eight possible positions. Next, connect up the rods to the advance lever, making sure that the whole range of movement is available after connecting up.

FIG. 65E. MARKS ON FRONT END PLATE AND LARGE DISTRIBUTOR WHEEL

Impulse Starter (see Fig. 66)

This device consists essentially of two members, the driving member,

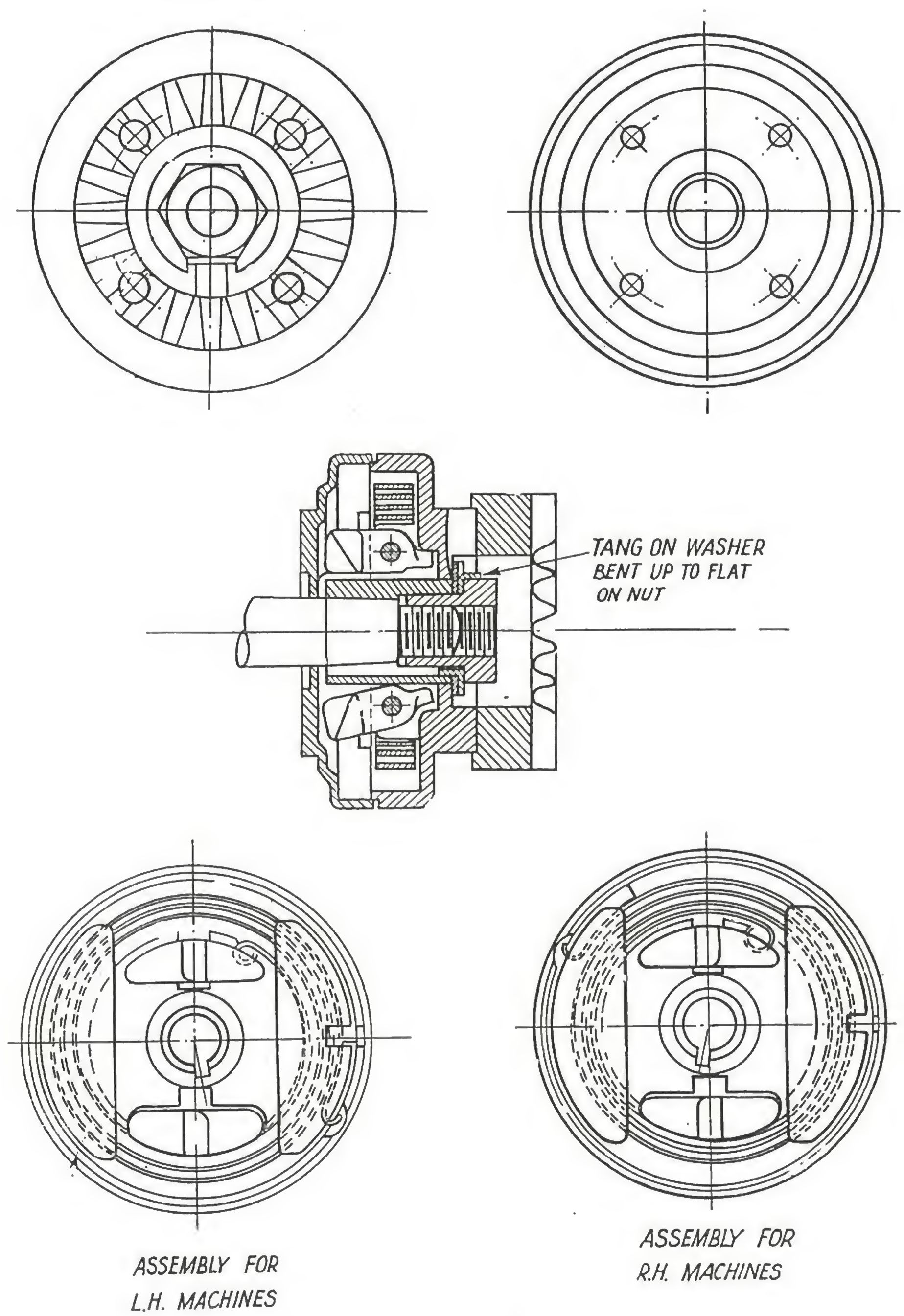


FIG. 66. IMPULSE STARTER. MAIN ASSEMBLY

which is coupled to the magneto driving shaft of the engine, and the hub assembly, which is rigidly secured to the magneto spindle.

The driving member and hub assembly are linked together with a stout helical spring. The hub carries two pawls, one end of which engages with the cam profile machined on the inside face of the driving member.

A special endplate is fitted to the driving end of the magneto and is provided with a stop.

The action of the impulse starter is as follows—

1. When the driving member is rotated, one of the pawls will reach the top position and, being free to drop, engages with the top of the end-plate. The armature and hub assembly are thus locked and held stationary.

2. Further rotation of the driving member will cause the helical spring to be wound up, and an angular displacement will take place between the driving member and hub assembly.

3. At a pre-determined position the cam on the inside face of the driving member engages with the outer end of the pawl and forces it inwards.

4. This disengages the pawl from the stop in the endplate, and, due to the winding up of the spring, the hub assembly, together with the armature, receives a sudden impulse. The magneto is timed so that the contacts separate during this very rapid "flick over" and an intense spark is thus automatically produced.

5. The pawls are so weighted that the heavy ends are thrown out by centrifugal force and automatically clear themselves from a further engagement with the stop on the endplate as soon as the engine accelerates. The speed at which this occurs is about 160 r.p.m. magneto speed.

6. As soon as the pawls cease to engage, the two members, i.e. the driving member and hub assembly, rotate as a single unit.

It should be specially noted that as two pawls are fitted, two impulses are obtained every revolution of the magneto driving shaft.

The A.G.4-2 magneto may be fitted with the Type "A" impulse starter. This starter is susceptible to end-thrust and it is therefore important that a slight amount of endplay (·02 in.) be allowed when fitting the rubber distance-piece in the Simms coupling. If any endthrust is exerted, the hub, after it has been released from the stop, will remain in this position and the impulse starter is then absolutely inoperative.

If it should be found at any time that the impulse starter is sticking and does not operate, the bolts fixing the magneto to the base plate of the engine should be released and the magneto moved slightly outward: there is sufficient clearance between the bolts and the bolt-holes to allow for this. The impulse starter will then immediately be released.

Two other points should be watched with this type of impulse starter, viz.—

(*a*) See that the driving pin is free in the guide block.

(*b*) See that the pawl is free on its bearing.

If either of these points is suspected, it will be necessary to dismantle the impulse starter by unscrewing the fixing nut; and to do this it is necessary to insert a locking pin in the hole in the impulse-starter casing.

A.G.4-4 magnetos are fitted with type "L.-2B." impulse starters, which is a smaller and lighter device of the "A" type. Both types are absolutely interchangeable, and therefore this lighter type can be fitted to magnetos already equipped with the "A" type, if necessary.

The "L.-2B." type impulse starter is not so susceptible to endthrust as the type "A," but although it will not adversely affect the functioning of the impulse starter, it is not advisable to exert endthrust.

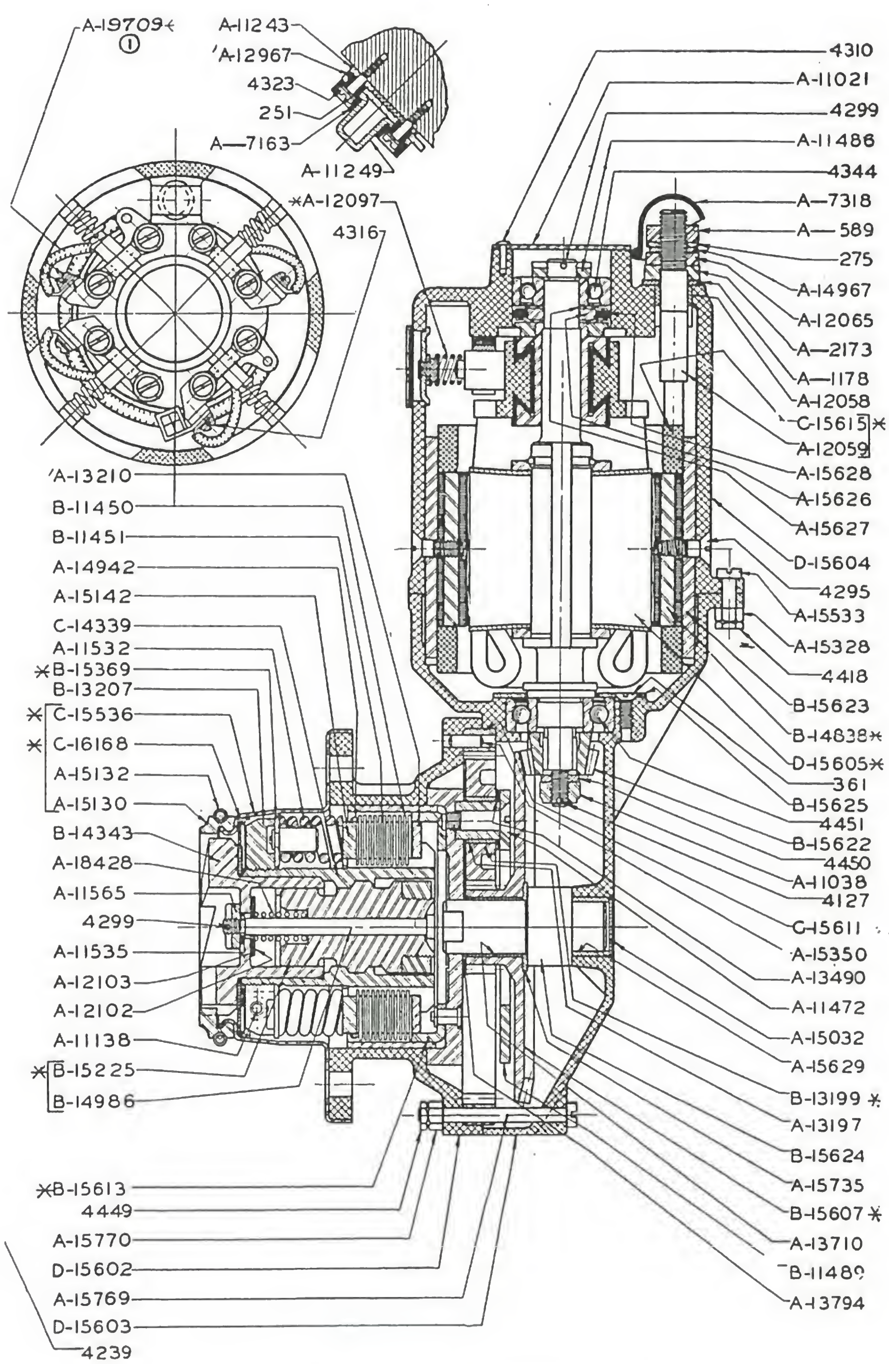


FIG. 67. ECLIPSE ELECTRIC STARTER

A.G.4-4 magnetos, not having any oiling system, can be fitted in an upright or inverted position. If, when this is done, either of the magnetos is fitted with an impulse starter, the stop on the back member must always be on top since the pawls are gravity-operated. Therefore, in order to distinguish which way up the magneto and impulse starter should be fitted, the word "*vertical*" or "*inverted*" is engraved on the back member of the impulse starter. The back member engraved with the word "*vertical*" indicates that the magneto should be fitted to either a Gipsy I or Gipsy II engine, and where the word "*inverted*" is engraved, it denotes that the magneto should be fitted to the Gipsy III engine.

This engraving on the impulse starter back-plate is applicable to those which have only one stop on this member; where two stops are provided, no special identification will be engraved externally, it being possible to operate these impulse starters either vertically or invertedly.

Timing of Impulse Starters

1. *Impulse Starters for Magnetos Rotating Clockwise.* Rotate the starter in a counter-clockwise direction until the two arrows, which are shown one on the starter endplate and one on the driving member, coincide. At the same time, see that the distributor brush is just overlapping the segment on No. 1 terminal. At this point, the contacts are just open with the timing lever advanced, and the sparking will take place on cylinder No. 1. Crank the engine to the desired firing angle and fix the magneto in this position.

2. *Impulse Starters for Magnetos Rotating Counter-clockwise.* Rotate the starter in a clockwise direction until the two arrows coincide, and proceed as in 1.

The only attention required during running, under normal conditions. is a few drops of machine oil occasionally inserted through the hole in the endplate.

Dismantling of Impulse Starter

The impulse starter is dismantled by unscrewing the one fixing nut which holds it to the spindle of the magneto. To do this it is necessary to insert a locking pin in the hole of the impulse starter casing. This locking pin should be used when assembling the impulse starter to tighten up the fixing nut, but it is vitally important that it should be removed before assembling the magneto on the engine.

Effect of Wear

Wear of the stops which retain the impulse unit B.T.H. Type L in position during normal running of the engine, i.e. when the unit is inoperative, has the effect of increasing the degree of advance of the ignition timing, and it is important that the advance shall at no time exceed that quoted on the engine data plate or in the instruction book.

The timing should, therefore, be periodically checked, and, if necessary, reset by means of the vernier coupling.

All details of the result of each examination should be entered in the log book, with particular reference to any adjustments made. An indication will thereby be provided of the extent, if any, to which the stops have worn.

Eclipse Electric Starter

The Eclipse Direct Cranking Electric Starter, Type Y-150, is furnished in the following models—

Model	*Rotation*
M. 2266	Clockwise
M. 2286	Anti-clockwise

The type Y-150 starter is designed to crank an engine continuously with the power available from a standard aircraft storage battery. It

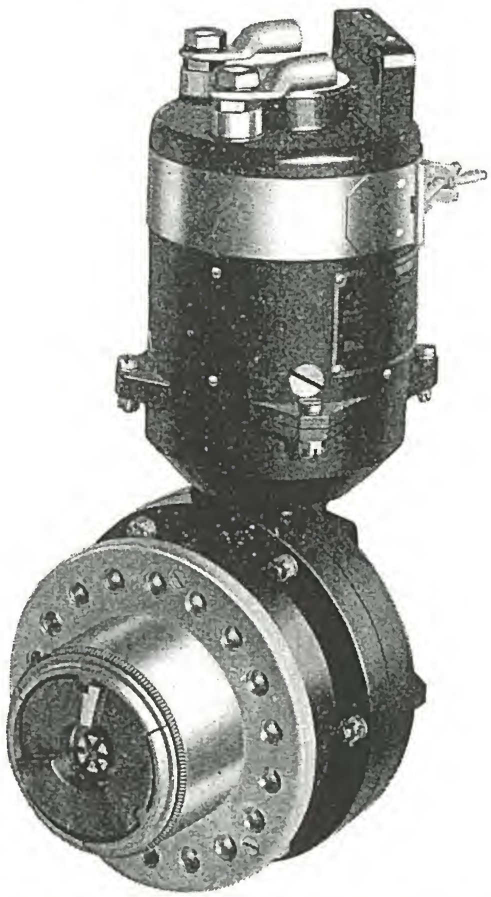


FIG. 68. ECLIPSE ELECTRIC STARTER UNIT

consists of an electric motor which drives reduction gearing operating an automatic meshing and demeshing mechanism through an adjustable torque overload release.

Referring to the cross-section (Fig. 67), it will be seen that a bevel pinion, mounted on the electric motor armature shaft, drives a bevel gear. This is integral with a spur pinion which meshes with three planetary gears. These are mounted on the barrel and run in a stationary gear fastened to the housing. The planetary gears drive the barrel containing the torque overload release, a spring-adjusted, multiple disc clutch. The externally splined clutch discs are driven by the barrel and the internally splined discs drive the spline nut. Threaded within this is the screw shaft which is caused to advance at the first rotation until the stop nut rests against the back end of the threads. The starter jaw advances with the screw shaft and meshes with the engine jaw. A friction brake is used to make the jaw advance into mesh before rotating. This consists of a three-

piece friction ring having tips which fit into corresponding slots in the jaw. It is held in place on the baffle plate by a spring of predetermined tension.

The rear faces of the starter jaw teeth are sloped so that when the engine starts the jaw is pushed out of mesh. The clutch is a safety device to allow only the desired amount of torque to be used for turning the engine over and also to protect the starter from possible damage in case the engine back-fires.

When starters are shipped from the factory a dust cover is sometimes mounted on the forward end over the starter jaw. It should not be removed until mounting the starter.

The Type Y-150 starter is applicable to engines having the standard 5 in. S.A.E. starter mounting flange. Six studs are located in this flange on a 4-in. bolt circle.

There should be approximately $\frac{3}{32}$ in. clearance between the engine jaw and the starter jaw when the latter is out of mesh. This should always be checked when fitting.

The flange on the starter is drilled with eighteen holes providing various positions 20° apart in which the starter can be mounted to give the best clearance. The starter will operate equally well in any position.

The starter may be operated from a 6-volt battery when used on engines up to 250 cub. in. displacement, but for engines from 250 to 450 cub. in. displacement a 12-volt battery must be used. The regular aircraft type non-spillable battery should be used, many makes of which are now available. It is difficult to make any recommendations on the size to be used as this will depend on the current required in addition to the starter, by landing lights, navigation and instrument lights.

The battery carrier should be located as close to the starter as convenient in order to simplify the wiring. It must be adequately vented.

The use of a solenoid switch is recommended where the Y-150 starter is at some distance from the push switch. In this type of installation an ordinary push switch in the cockpit is sufficient for the current which it will be required to carry. The wiring will consist of two circuits, the "battery-starter-solenoid" circuit, and the "solenoid-push-switch-battery" circuit.

If a solenoid switch is not used, a heavy duty push-switch must be installed. The circuit then is a simple series connection.

The engine manufacturer's instruction book should first be followed for preparation of the engine before starting.

Usually, the spark is at full advance and the throttle is slightly open when the starter is operated. If the engine fails to start readily the cause should be ascertained at once in order to avoid running the battery down. If it is required to unload the cylinders of their charge, the propeller should be pulled through one-third or one-half turn in its normal direction (switch off) to disengage the starter jaw. When released, the propeller may be turned in the opposite direction as required and then primed again for a new start.

All starters are sufficiently lubricated prior to shipment and should require no attention for a considerable period of service. Do not put oil on the commutator as it will seriously hinder the operation of, or cause considerable damage to, the motor.

The brushes should be inspected at 150-hour intervals to see that they are bearing on the commutator and that they do not bind in their respective holders. If such periodic examination should disclose worn brushes, they should be replaced immediately. Burning of the commutator and insulation usually results from failure to make such replacement in time.

The brush springs should also be examined and if they have lost their tension they should be replaced. The brushes should be under at least 20 oz. pressure.

Do not use emery cloth or rough sand-paper on the commutator. It can be polished with fine sand-paper. Make sure all sand particles are cleaned out before operating the motor. If the commutator becomes rough or burned, remove the armature and take a light, smooth cut across its face.

If the motor fails to operate, the trouble may be in the solenoid switch or the push switch. A jumper wire connected across the large terminals of the solenoid switch will make a direct circuit between the battery and starter. If the motor operates with this jumper wire, the solenoid or push switch is inoperative.

The bearings are lubricated with a good grade of neutral bearing grease.

The gears and clutch are lubricated with a light covering of No. 32 Gredag. It is highly important that no other lubricant be used.

All starter clutches are carefully set prior to shipping and should not require altering. The setting is determined by the size of the engine on which the starter is to be used and it requires special equipment.

An oil seal is incorporated in all starters to prevent seepage of oil from the engine crankcase into the starter housings. Engine oil will slow up the operation of the starter so that its performance is unsatisfactory.

A baffle plate is provided to cover completely the portion of the starter protruding into the crankcase, to protect the starter from oil splash. A leather seal is also assembled within the baffle plate back of the starter jaw in the event of the oil level, for any reason, approaching the opening in the baffle plate.

(B) Heavy Aircraft Magnetos

As indicated previously, for heavier aircraft engines the design of the magneto is radically modified and four sparks per revolution of the rotor are provided. This type of magneto falls into three sub-divisions—

1. Polar inductor type—where the flux is reversed in the rotor itself.
2. Polar inductor type—where the flux is reversed in the armature poles which carry a stationary coil.
3. Rotating magnet type—where the magnet itself is incorporated in the rotor assembly.

In all three types the general arrangement of components is identical, and they are arranged in easily accessible sub-assemblies.

Housing. This is a die casting and has cast in it the armature poles which protrude above the top face. This housing also contains the end-plate suitable for spigot mounting—or in the case of base-mounted magnetos, inserts in the base for fixing. The poles are laminated and sheet iron material is used so that the losses are reduced to a minimum. On these poles is fastened the armature assembly.

Armature. This is a bobbin having a laminated core with primary and secondary windings similar to the rotating armature type magneto. The primary usually contains about 200 turns of H.C.C. enamelled wire and the secondary approximately 10,000 turns of H.C.C. wire. A condenser is fastened to this bobbin and one side is connected to the insulated side of the primary and the other is connected to earth, the beginning of the primary winding having already been earthed in the bobbin; the secondary is brought out to the coil moulding. The distributor endplate is a separate die casting and spigots into the housing carrying one of the

rotor bearings, the other rotor bearing being integral with the housing. This endplate also carries the slow-speed wheel assembly.

Slow-speed Wheel Assembly. This is very similar to the one described for light aircraft, except that the brush holder makes direct contact with the coil moulding.

Distributor. This is a completely moulded unit and also spigots into the distributor endplate.

Rotor has four poles, which, in the case of the pure inductor magneto is laminated, as the flux has to be reversed in this rotor, and in the case of the other two types of magnetos is made of solid malleable cast iron of low hysteresis loss. In all cases a straight, though non-magnetic, shaft is used with the driving spindle at one end, and the cam operating the contact-breaker mechanism at the other. The rotating magnet rotor is a tubular, or in some cases a bar magnet, spigoted into the inductor fingers, thus providing a magnetic flux directly on those fingers. The inductor fingers are spaced 90 degrees apart, being alternately north and south. In the case of the pure inductor machine, pole inductor magnets are affixed to the housing, one or two on either side, the flux passes through laminated poles to the housing and the rotor. These magnets are usually of straight magnetic cobalt steel.

Contact-breaker. The contact-breaker mechanism is very similar to that used on light-weight magnetos, with a bell cranked lever having platinum iridium contacts affixed to it, and being controlled by a spring. This lever operates on a hardened steel pivot. Also affixed to the base is an insulated block which carries the adjustable contact. The primary from the insulated side of the condenser is taken by means of a lead to this insulated block through the endplate, contact being either permanent or through some sort of spring or plug connection. This contact-breaker lever is operated by a hardened cam which is fitted to the spindle and has four lobes. These lobes are so arranged that the contacts are held open for the correct period and closed for the correct period to allow the flux to build up to its maximum value. The whole of the contact-breaker is shielded by means of a pressed metal C.B. cover, in which is an insulated connection which connects to the block on the C.B. base, and forms a means of affixing the lead for earthing the magneto.

Timing of Magneto. The timing of this magneto is carried out in a similar manner to that described for lightweight magnetos, except that the contact-breaker base itself is moved, and an adjustable strap is provided in the endplate for setting the timing, all the parts, i.e. the cam, contact-breaker, keyways in the rotor, being so arranged that the timing is very nearly correct when the parts are assembled, and therefore this strap has only to be moved a relatively small distance to adjust the timing correctly.

Magnetos Types A.C. and S.C.

Types A.C. and S.C. magnetos belong to that distinctive class of high-tension magnetos known as the "Polar Inductor" type, and are provided with a stationary armature in which the current that produces the spark is generated. This current reaches a maximum four times during each revolution of the rotating member, called the polar inductor, and accordingly four sparks per revolution of the magneto shaft are produced. Types A.C. and S.C. magnetos are supplied in the following forms.

*A.C.*12. A base-mounted magneto suitable for 12-cylinder aeroplane engines, and provided with a trailing starting-point, the distributor having

protruding segments, and arranged for front fixing. The distributor and contact-breaker are fitted with metal shields arranged to accommodate metal-braided cable to standard specification. The low-tension lead (metal-

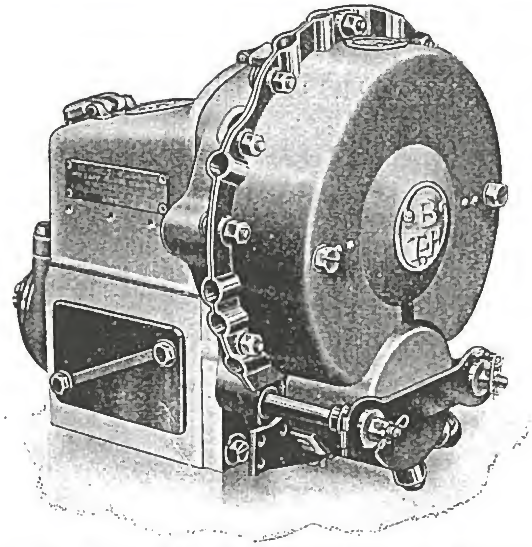


Fig. 69. Type A.C.12-1 Base-mounted Magneto
(By courtesy of B.T.-H. Co.)

braided) is connected to the contact-breaker in such a manner as to ensure the whole being effectively shielded. Variable or fixed ignition can be arranged as required.

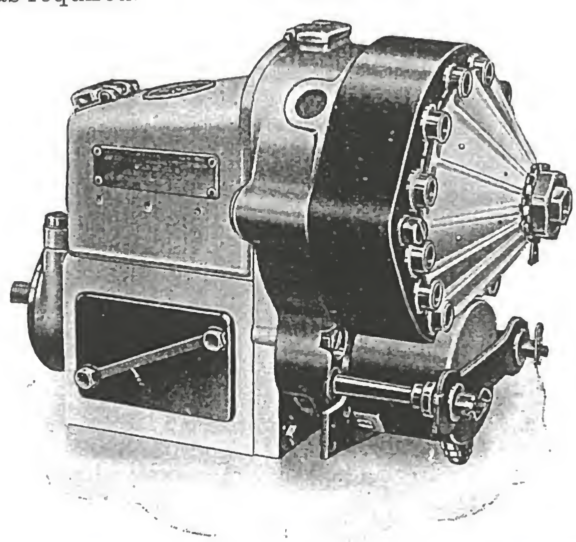


Fig. 70. Type A.C.12-9 Base-mounted Magneto
(By courtesy of B.T.-H. Co.)

*S.C.*12. Similar to A.C.12, but designed for spigot mounting, and having an oil-tight gland in the driving endplate, preventing oil under pressure in the crankcase from being forced into the interior of the magneto.

Shields for contact-breaker and distributor are embodied similar to those on the A.C.12 magneto.

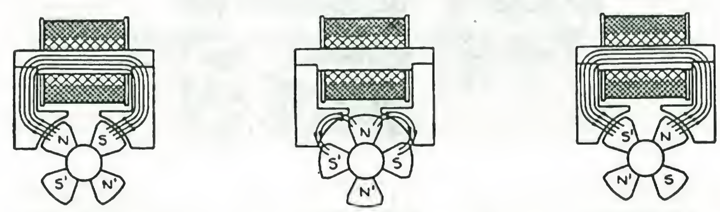
The above two magnetos can be supplied with distributors arranged for the ignition cable to be brought out either in an axial or a radial direction. They can also be supplied unshielded.

*S.C.*14. Similar to S.C.12 but designed for a 14-cylinder engine. This magneto can only be supplied with high-tension leads of the distributor brought out in an axial direction, but can be supplied unshielded.

*S.C.*10-1. Similar to type S.C.14, but designed for 10-cylinder engines. The distributors are arranged for the ignition cables to be brought out in an axial direction only. This type of magneto is driven at $1\frac{1}{4}$ times engine speed, and is supplied to operate as right- or left-hand machines.

*S.C.*9. Similar to S.C.14, but designed for a 9-cylinder engine.

*S.C.*7. Similar to S.C.14, but designed for a 7-cylinder engine.



POSITION 1
FLUX THROUGH WINDINGS
A MAXIMUM

POSITION 2
FLUX THROUGH WINDINGS
ZERO

POSITION 3
FLUX THROUGH WINDINGS
A MAXIMUM (reversed)

FIG. 71

Each type can be supplied for either right- or left-hand rotation as required. The shaft extension is always provided with a taper of 1 in 10. For standard base-mounted magnetos the distance between the centre line of the shaft and the bottom of the base plate is 45 mm.

Owing to the special arrangement of the Type A.C. and S.C. magnetos, dismantling can be carried out with very great ease. The design is such that the various screws and the different components, which are grouped to form distinctive sub-assemblies, are readily accessible. The magnetos are fitted with "straight through" steel shafts on which the rotating inductors are mounted, forming an excellent mechanical construction specially adapted to withstand the severe vibration met with in service on aeroplane engines. The rotor requires no fixing screws.

Low Speed. As there are four sparks per revolution of the shaft the magneto operates at half the speed at which a rotating armature type of magneto (suitable for a corresponding number of cylinders) is driven. This conduces to long life of the various moving parts.

The low-speed sparking characteristics of the magneto are extraordinarily good, and starting is therefore facilitated.

Rotating Safety Spark Gap. The safety spark gap electrodes are mounted on the half-speed wheel of the magneto, and thus when the machine is in operation these electrodes are constantly sweeping through the air, by which means undue ionization is entirely avoided.

Ample Leakage Surface and No Brushes. Owing to the fact that the windings do not rotate, no slip-ring is required, and the leakage surfaces are appreciably in excess of those provided in rotating armature magnetos. These two features ensure immunity from internal electrical leakage.

Stationary Armature and Laminated Iron Circuit. As previously stated,

the armature of this magneto is stationary. It can be easily removed, and is designed to give unusually large safety factors in the winding.

The entire iron circuit, in which the flux reversal occurs, is laminated,

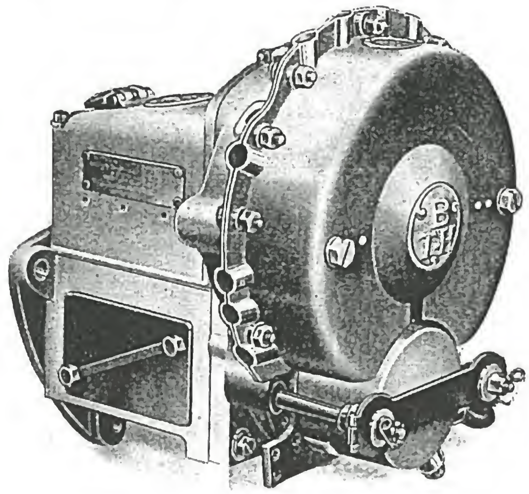


FIG. 72. TYPE S.C.12-7 SPIGOT-MOUNTED MAGNETO
(*By courtesy of B.T.-H. Co.*)

thus giving a very rapid rise of voltage at "break" and resulting in increased intensity of the spark.

Distributor. A special type of distributor is provided operating with a small spark gap between the rotating metal brush and the segments, the

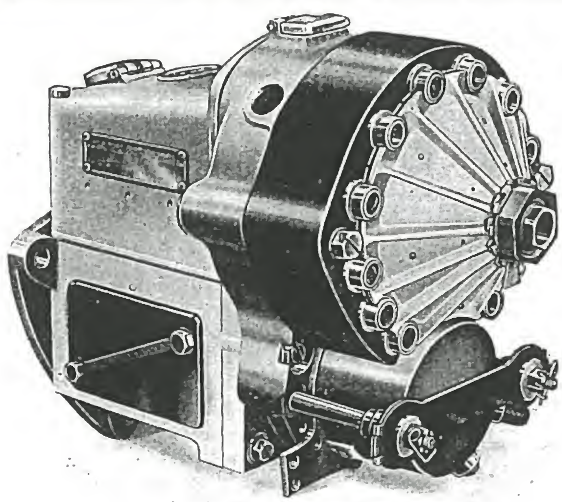


FIG. 73. TYPE S.C.12-10 SPIGOT-MOUNTED MAGNETO
(*By courtesy of B.T.-H. Co.*)

latter being arranged to protrude well beyond the surface of the material. With distributors of this design "tracking" cannot occur.

The distributor used on the Types A.C. and S.C. magnetos is fastened to the magneto by means of two set screws which are screwed into bronze

inserts located in the aluminium end-casting. In addition these machines have a metal shield which completely screens the distributor and contact-breaker to prevent interference with wireless apparatus installed on the aeroplane.

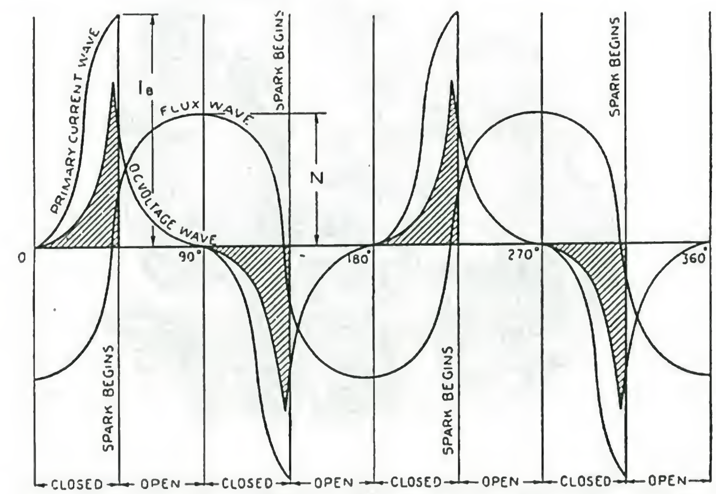


FIG. 74. FLUX AND VOLTAGE WAVES IN ONE REVOLUTION
(*By courtesy of B.T.-H. Co.*)

The whole range of these aircraft magnetos are designed for use with metal-braided cable, but, by the introduction of special cable fittings, plain rubber cable may be used.

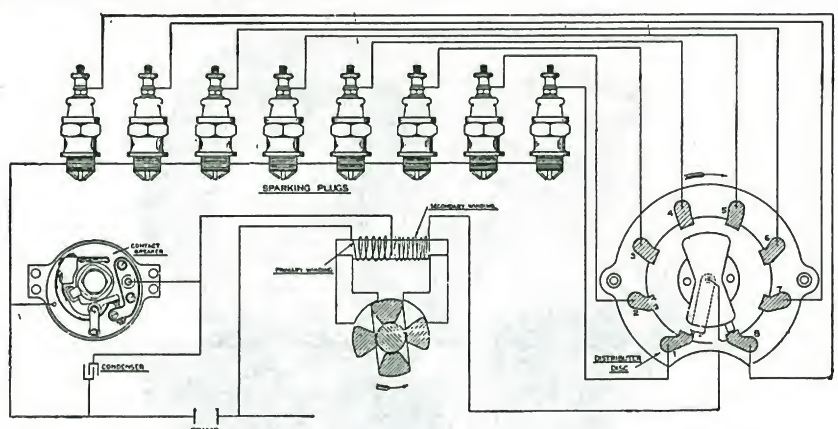


FIG. 75. CONNECTION DIAGRAM FOR SINGLE-POINT IGNITION
NOTE. The order of the plugs does not denote the numbering of the cylinders commonly adopted.
(*By courtesy of B.T.-H. Co.*)

LIGHT-WEIGHT MAGNETOS

Where magnetos of exceptionally light weight are required, as for racing machine engines, all types of magneto can be supplied with the main castings made of Ultra-light Magnesium Alloy. These magnetos are unshielded and the distributors are suitable for use with plain high-tension leads.

DESCRIPTION AND OPERATION

Magnets and Flux Distribution. Two cobalt steel magnets having phenomenally high magnetic characteristics are fitted on the sides of the main body casting, and make intimate contact with the two laminated annular poles at each end of the body casting. The poles of the magnets are disposed axially so that the two laminated poles at the ends of the body casting are of opposite magnetic polarity. The flux enters the annular end of the rotating inductors via the small air gap, passing through the inductors to the armature core. The reversal of the magnetic flux in the armature core is effected by the rotation of the inductors or fingers in the manner illustrated in Fig. 71, from which it will be seen that there are four complete reversals of flux in the armature core for every revolution of the rotor shaft. Fig. 74 shows flux and voltage waves produced.

Relative Speed and Direction of Rotation. The type S.C.7 magneto is driven at $\frac{7}{8}$ engine speed, the type S.C.9 at $1\frac{1}{8}$ engine speed, the types S.C.12 and A.C.12 at $1\frac{1}{2}$ engine speed, and the type S.C.14 at $1\frac{3}{4}$ engine speed. All these magnetos can be supplied to operate as right- or left-hand machines as conditions demand, and are suitable for operating in pairs on engines arranged for dual ignition.

Primary Winding. The beginning of the primary winding is connected to the armature core or earth, and the end is connected to the beginning of the secondary winding and to the contact-breaker. The cam operates the rocker arm, separating the contacts four times per revolution of the shaft. When the contacts are closed the primary winding is short-circuited, and as the inductor rotates, the current induced in the primary winding builds up until the cam separates the contacts at the instant when this current is at a maximum. The instantaneous collapse and reversal of the flux at the moment of "break" produces the high voltage in the secondary winding which causes the spark.

Secondary Winding. As previously mentioned, the beginning of the secondary winding is connected to the end of the primary winding, and the end of the secondary winding is connected to the small brass insert in the armature coil moulding. This insert makes contact with the collector brush, which is in turn connected to the rotating metal brush. The spark leaps from the rotating brush to the various segments as the brush rotates, and thus the ignition sparks are distributed to the various plugs on the engine. These connections will be clearly understood on reference to Fig. 75. It should be particularly noted, however, that the order of the plugs as shown in the diagram does not necessarily agree with the numbering of the cylinders commonly adopted.

Safety Spark Gap. The safety spark gap is one of the special features in the design of this type of magneto. Should any connecting lead become disconnected from its plug, undue rise of voltage, which might damage the insulation of the magneto, is guarded against by the provision of the safety gap across which the spark may discharge when there is no alternative gap between the spark plug electrodes. A brass point protrudes from the distributing brush box towards the slow-speed gear-wheel, and a serrated stud, screwed into the gear-wheel, constitutes the other pole of the gap. Owing to the fact that this gap is always rotating, the air between the electrodes is in a constant state of commotion, and thus ionization is reduced to a minimum. Furthermore, the machines are provided with suitable means of ventilation so that the air in the machines is constantly being changed. These features ensure that the spark gap will be reliable in practice.

Contact-breaker. It is necessary to close and open the primary circuit four times during each revolution of the rotor shaft, and this is effected by means of a four-point cam which is mounted on the end of the shaft.

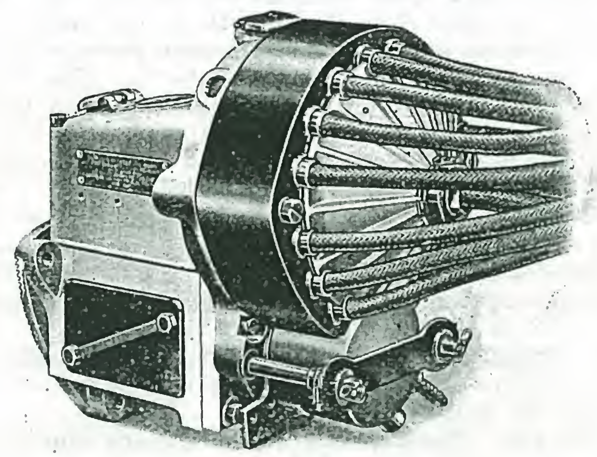


FIG. 76. TYPE S.C.14-1 SPIGOT-MOUNTED MAGNETO
(By courtesy of B.T.-H. Co.)

This cam operates a bell-crank lever, the end of which carries the movable contact. When the lever is deflected by the cam the distance between the platinum points should not be greater than 0·012 in., and this should be checked from time to time, and adjusted, if necessary, as instructed under "Location of Faults."

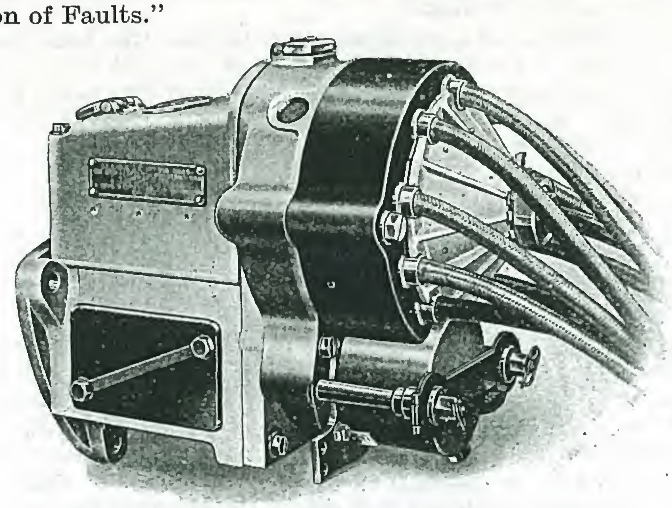


FIG. 77. TYPE S.C.9-1 SPIGOT-MOUNTED MAGNETO
(By courtesy of B.T.-H. Co.)

The usual form of fibre bush is replaced by a bronze bush lubricated by means of a small oil wick fitted inside the bearing pin. There is a radial hole in the pin so that oil from the wick can flow outwards and lubricate the bearing surface.

Installation. Fix the driving gear wheel or coupling to the magneto shaft, set the engine to the correct firing position on No. 1 cylinder, and adjust the coupling or gear wheel of the magneto shaft so that proper engagement occurs. With the contact-breaker lever in the "fully advanced" position the contacts should be just separated (by not more than

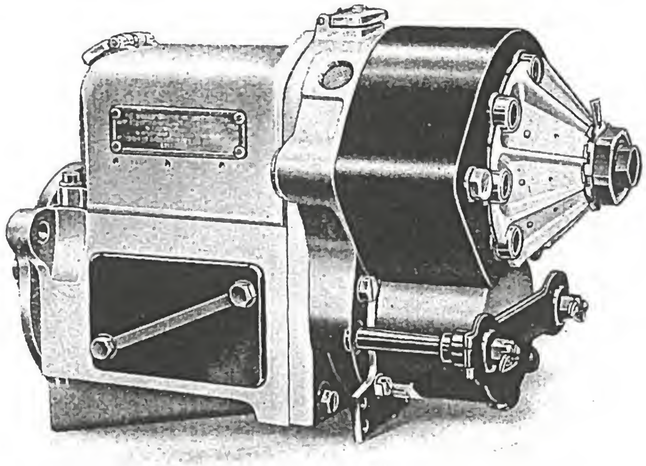


FIG. 78. TYPE S.C.7-1 SPIGOT-MOUNTED MAGNETO

0·0015 in.) and the distributor brush should be just overlapping the segment of the distributor marked No. 1.

Base-mounted machines should be secured to the platform by inserting loosely two of the fixing screws, and the engine then turned several times while the magneto is observed closely, to determine whether any movement occurs.

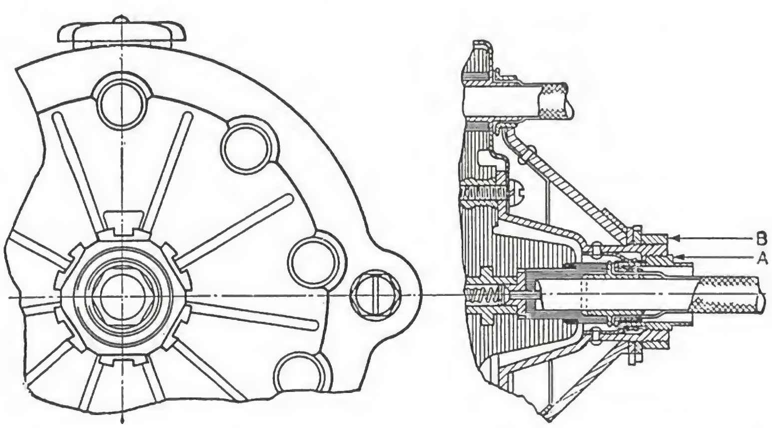


FIG. 79. SECTIONAL VIEW OF DISTRIBUTOR AND CLAMPING PLATE

ment occurs. If any movement is observed, it is an indication that the coupling is not in correct alignment, and this fault must be rectified before anything further is done. It is most important that no stress be thrown on the driving spindle of the magneto due to incorrect alignment of the coupling. When it is established that the magneto and engine shafts are in perfect alignment, the fixing screws should be tightened.

On spigot-mounted magnetos the allowable tolerance on the spigot, and the spacing of the three fixing holes in the flange are in accordance with the limits specified by the B.E.S.A. specification.

Cutting Out the Magneto. The low-tension terminal is connected to the end of the primary winding so that the magneto may be cut out of action by simply connecting this terminal to earth by means of a suitably located switch. An insulated insert connected to the outside end of the primary winding is contained in the moulding situated in the contact-breaker cover. A suitable terminal is also provided on the cover for connecting the earthing lead.

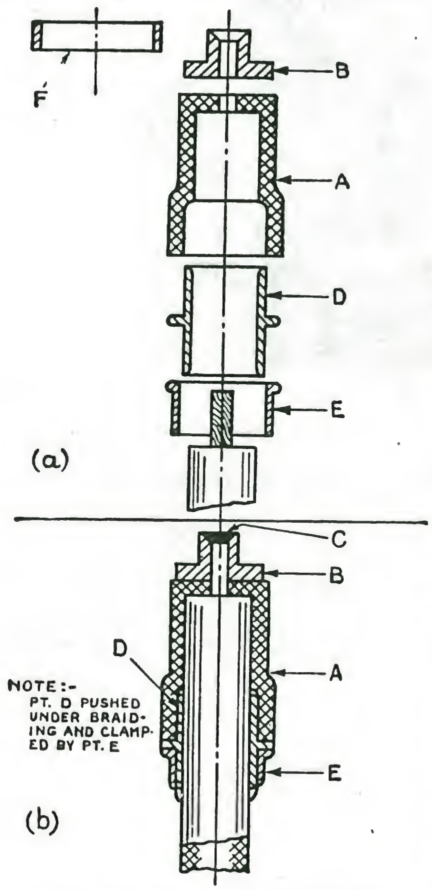


FIG. 80. DIAGRAM SHOWING METHOD OF ASSEMBLING DISTRIBUTOR LEADS

Contact-breaker. The magnetos are intended to operate with gaps of approximately 0·012 in. between the contact points, and the permissible tolerance on different points of the cams should not exceed 0·0015 in. This means that the minimum gap between the contacts may be 0·0115 in., and the maximum gap 0·013 in.

It is of the utmost importance that the platinum contacts be kept absolutely free from oil, because if any oil is present it becomes oxidized and prevents the contacts from making good electrical contact when closed.

When necessary the contact points may be cleaned with very fine emery cloth, but under no circumstances should they be filed. They may be taken out and carefully trued up in the lathe, with a hand tool, if they become pitted. Great care must be taken that they make good contact with one another.

Distributor. As no contact with the track of the distributor is made and the high-tension arc is not struck close to the moulded material, cleaning is seldom necessary, but it is advisable to dust out the distributor when an examination of the magneto is made, say every 25 hr. In the event of any adjustment being made to the metal-distributing electrode it is necessary to ensure that this electrode does not foul the distributing segments. The correct clearance is 0·016 in. to 0·02 in., and the pitch of the screw for adjusting the brush is such that a quarter of a turn moves the brush approximately 0·004 in. In order to check this clearance all the distributor terminals should be short-circuited by means of a wire, and connected in series with a bell and battery to the contact-breaker terminal. The screw securing the brush-holder sparking electrode should then be turned until, on rotating the magneto, the bell rings on say two or three segments. If the screw is now screwed in a minimum of 1 and a maximum of $1\frac{1}{4}$ turns this adjustment will be correctly made.

Assembling Distributor Leads. When fitting the high-tension metal-braided leads to the distributor proceed as follows—

1. Remove the clamping plate which secures the leads in position in their respective sockets after first unscrewing the centre nuts *A* and *B*. (See Fig. 79.) *A* is the nut securing the starter lead, and *B* the nut securing the remaining leads in position.
2. Cut cable to length to suit respective cylinders.
3. The cable fittings fit over the ends of the cable (see Fig. 80). Remove metal braiding for 30 mm. and fix standard cable fittings *D* and *E*. Slip distance piece *A* over the cambric covering. Bare cable for distance of

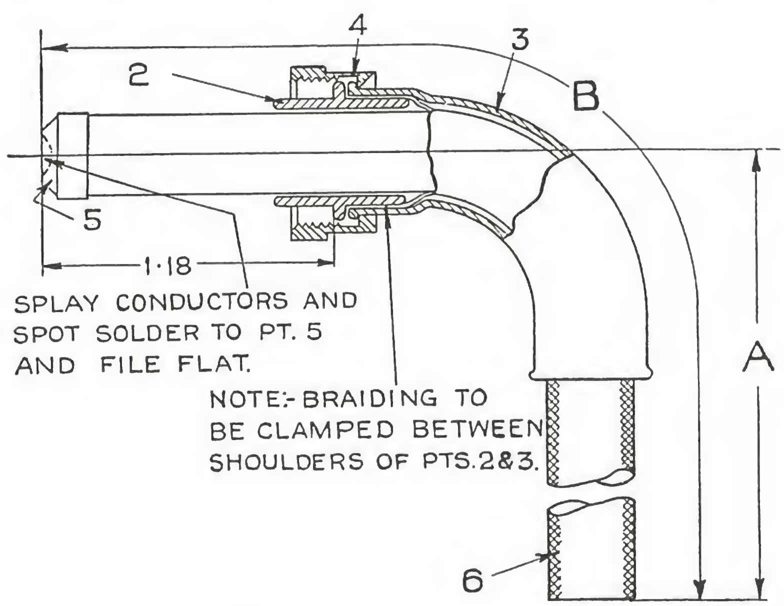


FIG. 81. HIGH-TENSION LEAD ASSEMBLY FOR TYPE S.C.9 AND S.C.10 MAGNETOS

7 mm., slip on nipple *B*, and carefully solder at *C*. All surplus solder to be removed, otherwise a good fit in the socket is not guaranteed.

Before fixing the above leads it is necessary to place the rubber glands *F* in the sockets of the distributor so that they rest on the ledge. The leads may then be pushed home and clamped, but care must be taken to ensure that the glands are not pushed into the sleeve beyond the ledge. It is important that the clamping plate holds all the distributor leads perfectly rigid.

When assembling the high-tension leads to type S.C.9 or type S.C.10 magnetos, proceed as follows (see Fig. 81). (*a*) Cut cable to length to suit respective cylinders; (*b*) remove metal braiding for 32 mm. and bare cable for a distance of 4 mm. Insert part 2 under braiding and clamp with part 3. Slip on part 5, splay conductors and spot solder and file flat. Slip on part 4. The dimension 1·18 in. shown is important, since efficient electrical contact is dependent on it. This only applies in such cases where the above type magnetos have the high-tension metal-braided cables fitted to the distributor independently of each other, and each lead is extracted from the distributor by removing its securing nut.

Cable Specification. Metal-braided high-tension cable, specification E.1, section 2, latest issue (R.A.E. Addendum E/E76), No. of wires 40. Diameter of wires, ·010 in. Outside diameter of cable, ·355″ L to ·375″ H.

Lubrication. Too frequent lubrication is not desirable in the case of types A.C. and S.C. magnetos. It will be satisfactory if the magneto is lubricated every 200 hr. as follows: six drops of oil to be introduced into the oil cup at the driving end, and six drops in each hole situated under

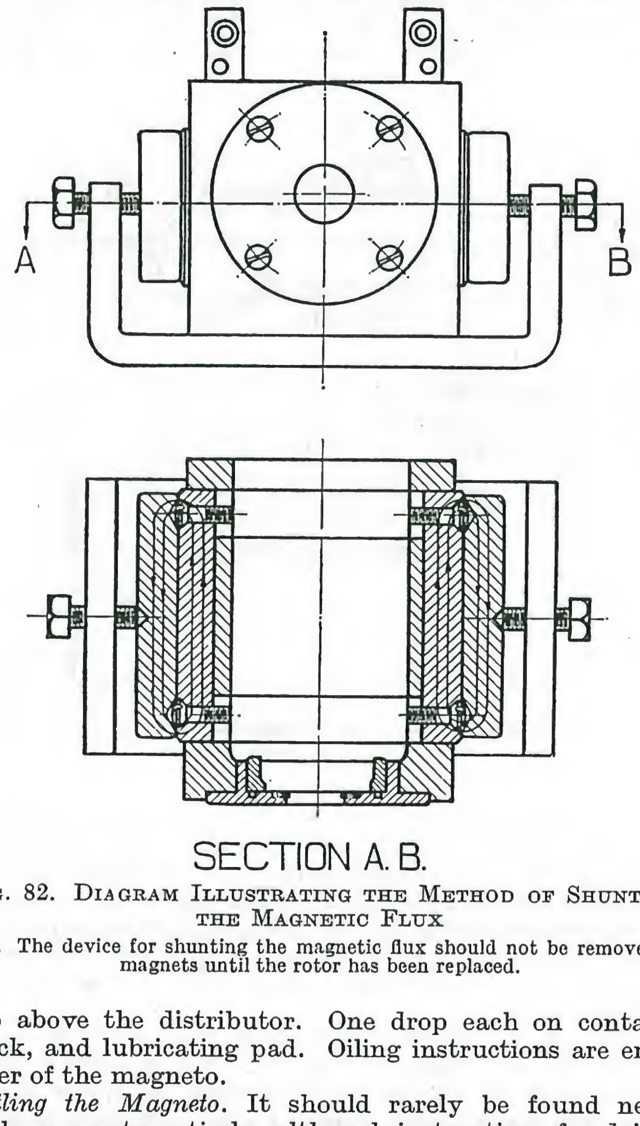


FIG. 82. DIAGRAM ILLUSTRATING THE METHOD OF SHUNTING THE MAGNETIC FLUX

IMPORTANT. The device for shunting the magnetic flux should not be removed from the magnets until the rotor has been replaced.

the oil flap above the distributor. One drop each on contact-breaker, bearing, wick, and lubricating pad. Oiling instructions are embossed on the top cover of the magneto.

Dismantling the Magneto. It should rarely be found necessary to dismantle the magneto entirely, although instructions for doing this are given below. In the ordinary way, apart from occasional lubrication, attention need only be given to the distributor and contact-breaker. Both of these components are readily accessible, and can be quickly removed and replaced without disturbing any of the working parts. In dismantling the magneto the following procedure should be closely adhered to—

1. Disconnect the low-tension lead at the point where it is connected

to the low-tension terminal on the contact-breaker cover and then remove the contact-breaker base, timing lever, and cover, as a single unit.

2. Remove the fixing screws holding the distributor to the endplate and remove the distributor and shielding as one unit.

3. Remove the main cover.

4. Disconnect the low-tension lead at the point where it is connected to the condenser, by slackening the two clamping screws.

5. The armature and condenser sub-assembly are the next to be removed.

6. Take out the four fixing screws which secure the distributor gear-wheel assembly to the aluminium distributor endplate, when the complete unit can be withdrawn.

With the magneto in this state it may be again reassembled without the necessity for remagnetizing to ensure satisfactory running, but if it is required to remove the rotor, the machine will require remagnetizing unless special precautions are taken to retain the flux in the magnets. These precautions consist of shunting the flux through soft iron keepers before actually removing the rotor, and Fig. 82 shows diagrammatically a suitable device for this purpose.

Should it be desired to remove the rotor, proceed as follows—

7. Unscrew the hexagon-headed cam fixing screw and remove the cam with the aid of a special extractor which can be provided for that purpose. The full speed gear-wheel can now be withdrawn by means of an extractor provided for this purpose.

8. Remove the four fixing screws securing the distributor endplate to the housing, and gently tap the rotor spindle at the driving end with a wooden mallet. The distributor endplate will be found to come away from the housing and the rotor can be withdrawn.

Running Overhauls. When the magneto has been dismantled the various parts should be washed in clean petrol. The armature and condenser assembly, being well sheltered from oil and grease, should not require washing, and a wipe over with a clean dry cloth should suffice.

If the rotor has been removed, the ball-bearings should be smeared with good quality lubricating grease before assembling in the housing. Price's H.M.P. grease is recommended for this purpose.

When fitting the distributor gear-wheel sub-assembly great care should be exercised to ensure the correct meshing of the two gear-wheels. The two teeth which are spotted on the larger wheel must embrace the spotted tooth on the smaller wheel.

Great care should be exercised when replacing the armature sub-assembly to see that the small carbon brush is in place in the stem of the distributor brush-holder, and that it is not broken during the operation.

Mouldings which are cracked should be replaced.

Reversing Direction of Rotation. Any magneto can be changed from one direction of rotation to the other by replacing certain components and re-timing the magneto for the opposite hand. As this operation is one of considerable delicacy the magneto should in every case of this kind be returned to the manufacturers, who will make the necessary changes and re-test the magneto before returning it.

Location of Faults

When trouble occurs with the ignition system of the engine it does not necessarily indicate that the magneto is at fault. Incorrect clearance of the valve tappets or incorrect compression of the cylinders may cause irregular firing of the engine. Irregular firing may also result from faulty

sparking plugs or from defective operation of the contact-breaker of the magneto.

Ignition troubles fall into two categories: (*a*) local misfiring, which is generally confined to one cylinder, although it may occur in two; and (*b*) general misfiring, which may be evidenced by a scattered misfiring or a complete shut-down of the engine.

When looking for local trouble, the cylinder which is misfiring can be found by the well-known method of "shorting out" the plugs, one at a time, until the faulty cylinder is found. The short-circuiting of a defective plug will not further affect the running of the engine, but if the plug is performing its duty properly, then an immediate reduction of engine revolutions will be noticed when it is short-circuited. Having located the cylinder which is misfiring, remove the high-tension wire from the sparking plug and hold its end within $\frac{1}{8}$ in. of the wall of the cylinder and observe whether a spark jumps the gap with the engine running. If a strong spark passes, remove the sparking plug and replace it with a plug known to be in good condition. If this does not cure the trouble it is not due to the ignition system. If no spark, or only a weak spark, is observed, disconnect the wire from the distributor block, and see if the magneto is delivering a good spark to the lead. If it does not give a good spark, then the trouble is in the distributor block, and this may be due to dirt or oil. Clean the distributor, and if there is still no spark, then the distributor is faulty. If a good spark is delivered to the lead, then the lead is faulty.

Faulty sparking plugs are usually either the result of sooting up, or are caused by the electrodes burning away, thus causing the length of arc (and, correspondingly, the voltage necessary to produce a spark) to be too great. It is even possible, in the case of a leaky plug, for so much heat to be generated by the escaping gases as to cause burning of the insulation and melting of the electrodes.

The most common reason for local misfiring on two cylinders is due to the high-tension wires being attached in an incorrect order.

Spark plugs can sometimes cause local misfiring which is hard to locate, especially when it does not occur regularly. If the spark plug points are set too far apart, the engine will be difficult to start and will misfire at high speeds; if set too closely, the engine will start easily but will throttle very poorly. The gap should be set to 0·4 mm. approximately (= ·016″).

When general misfiring is experienced, remove the magneto from the engine and test it on spark gaps, and if the spark is weak or absent, then there is an internal fault in the magneto. If there is a good spark, then the magneto is in good condition so far as the general trouble is concerned.

If sparking persistently occurs at the safety gap of the magneto, it is an indication that there is a break in the external high-tension circuit.

If the engine stops firing altogether, it is probably due to the conductor from the low-tension earthing terminal of the magneto coming into contact with the frame.

The low-tension lead connection must be rigidly clamped under the insulated terminal nut fixed to the contact-breaker cover, and also at the point where it is connected to the condenser. This lead serves to connect the primary winding of the armature to the contact-breaker, and, therefore, any faulty connection will interfere with the satisfactory operation of the magneto.

If the engine is running at a normal speed under load, the timing lever should be in the "fully advanced" position. The position of the lever

Defect	Possible Causes	Effect
(1) Small contact gaps.	(*a*) Bad adjustment. (*b*) Wear of fibre heel. (*c*) Wear of cam. (*d*) Pitting of contact faces.	Retarding effect on magneto timing. Poor low speed results. Arcing at contacts.
(2) Large contact gaps.	(*a*) Bad adjustment. (*b*) Contacts worn. Sometimes due to excess in spring pressure. (*c*) Insulated block not secure.	Advancing effect upon magneto timing. If excessively large will tend to cause firing to cut out in fully advanced position.
(3) Contacts pitted or blackened.	(*a*) Oil or foreign matter on contact faces: (1) through use of dirty feelers; (2) excess of oil on contact-breaker generally. (*b*) Rocker-arm movement sluggish. (*c*) Weak control spring. (*d*) Rocker arm too loose or too tight a fit on the bearing bush. (*e*) Rough contact faces. (*f*) Contact loose in either rocker arm or insulated block. (*g*) Timing out—too far retarded. (*h*) Magneto being run continually in retarded position. (*i*) Contact-breaker making bad contact inside top of condenser endplate. (*j*) Primary connection to condenser not good. (*k*) Condenser earth connection loose. (*l*) Condenser loose in clips. (*m*) Condenser defective. (*n*) Contacts badly out of line or not parallel. (*o*) Bad metal in contacts.	Excessive arcing at contacts. Poor low speed results. If very bad, causes misfiring at high speeds. Erratic firing.
(4) Broken spring.	(*a*) Kinked, badly shaped, or brittle springs. (*b*) Rusting of spring.	Usually cuts sparking out altogether.
(5) Fibre bush of insulated block cracked.	(*a*) Faulty bush. (*b*) Excessive force used in tightening of screw.	May cut out sparking altogether.
(6) Seizure of rocker arm.	Lack of lubrication.	No spark.

should, therefore, be examined to see that it is correct, for if the lever be inadvertently pushed to the "fully retarded" position the sparking characteristics of the magneto will not be so good.

The cable for each high-tension connection should be pushed right home into the hole in the distributor, and firmly secured by means of the clamping plate and fixing nuts. It is advisable to examine these high-tension connections from time to time.

It is most important to check the gap between the contacts when the fibre heel on the contact-breaker lever is resting on a cam point. The

gap should be nominally ·012 in., and the actual gap should not exceed ·013 in. maximum or ·0115 in. minimum. The gauge provided is exactly ·012 in. thick, so that by introducing this between the contact faces it is an easy matter to determine whether the gap is correct. If the gap is appreciably in error it will seriously interfere with the functioning of the magneto, and any discrepancy of this kind should be most carefully put right by adjusting the contact screw carried by the insulated brass block on the contact-breaker base until the desired gap, as measured by means of the feeler gauge, is obtained.

Before condemning the magneto as being responsible for lack of ignition, always check the ignition switch and make sure that it, or some of its wiring, is not at fault.

As previously mentioned, irregular firing might result from defective operation of the contact-breaker, and the following table gives contact-breaker defects, how caused, and their effect upon the functioning of the magneto.

A classification of ignition troubles is as follows—

FAULTY SPARKING

1. Contact point clearance incorrect.
2. Breaker points burned or dirty.
3. Distributor brush burnt away.
4. Distributor segments burnt away.
5. Distributor block dirty.
6. Distributor out of time with armature.
7. Safety gap clearance insufficient.
8. Condenser short-circuited or punctured.
9. Magnets weak.
10. Loose or corroded connections inside the magneto.
11. Faulty earthing switch.
12. Moisture inside the magneto.

MAGNETO FAILS TO DELIVER SPARK

1. Primary open-circuited or earthed.
2. Secondary open-circuited or earthed.
3. Earthing switch closed.
4. Distributor block short-circuited.
5. Brush-holder short-circuited.

Complete Overhaul and Repair of Magnetos

When dismantling the magneto for overhaul or repair, it should be first dismantled into its sub-assemblies, and generally in this condition most of the parts can be inspected for flaws and wear. Mouldings which are cracked should be replaced.

After a magneto has completed 500 hr. running it is generally necessary to repack the slow-speed bearing with grease, but this should be the only time when it is necessary to dismantle this bearing assembly.

Magnetos on reassembly should of course be remagnetized, unless the magnets have been shorted by a soft iron keeper prior to dismantling the machine—this practice should be carried out where no magnetizing facilities are available.

After reassembly, the magnetos should be run for 4 hr. or 8 hr. sparking across standard approved gaps—described later. The magneto should be run for 8 hr. when any important insulated part such as the distributor, brush-holder, slip-ring, or high-tension collector moulding has been re-

placed; replacement of armatures, condensers, and contact-breaker levers also necessitates 8 hr. endurance run.

The normal test speeds for these magnetos are—

Sparks per Revolution	No. of H.T. Terminals	Speed
2	1– 6	3,500 r.p.m.
2	7– 9	4,000 ,,
4	6– 8	2,500 ,,
4	9–12	3,500 ,,
4	14–18	4,000 ,,
6	8–12	2,500 ,,
6	14–18	3,500 ,,
8	16–24	3,500 ,,

Immediately after the endurance run the magneto will run at normal test speed with all distributor leads disconnected and must spark over the safety gap only. This test is carried out with the magneto still hot. The maximum temperature during the endurance run should not exceed 40° rise in temperate climates.

After the above tests the magneto should be examined to see that no faults have developed. The magneto should then be tested to see that at a speed of 350 r.p.m., with each lead connected to a standard approved gap, the magneto sparks regularly, and over a period of 1 min., the percentage of misses should not exceed 1 per cent of the total number of sparks produced in that time. This condition applies to both advance and retard for magnetos having a 15 degrees timing range, and where a 30 degrees timing range is employed, a speed of 600 r.p.m. in the full retard is permitted.

Spark Gaps for Testing Magnetos (see Fig. 83). Spark gaps used in the testing of magnetos are of two kinds—annular and ball gaps. The annular gap is more suitable for endurance tests, whilst the ball gap is very satisfactory for low-speed tests.

In order to ensure that the low-speed performance of the magneto is correctly determined, it is important that the insulated third point be always maintained sharp and correctly set.

Hand Starter Magnetos. These magnetos are of the rotating armature type and are operated by hand through a 5 : 1 gear reduction. The armature and contact-breaker mechanism is exactly the same as for the standard type of magneto, and the high-tension current is collected direct from the slip-ring through collector mouldings fitted to the side of the housing—one on either side. The gear on the armature is cut integral with the spindle, to obtain the smallest possible diameter. The slow-speed wheel, to which is fastened the handle, is of Textolite and is housed in an endplate at the opposite end to the contact-breaker mechanism.

Automatic Timing Device (see Fig. 84)

Certain magnetos are fixed so far as the contact-breaker mechanism is concerned and an A.T.D. is used to advance the magneto timing relative to the engine crankshaft. These A.T.D.'s are usually of the centrifugally operated type.

The device consists of two members—the driving member, on which is fitted the weights carrying hardened steel rollers, which rollers engage the surfaces of the cam fitted on the other member, called the magneto member, which part fits directly to the spindle of the magneto.

The driving member works on a bearing formed by the spindle of the magneto member, the whole device being locked to the magneto spindle by means of a nut. Bosses on both magneto and driving members are

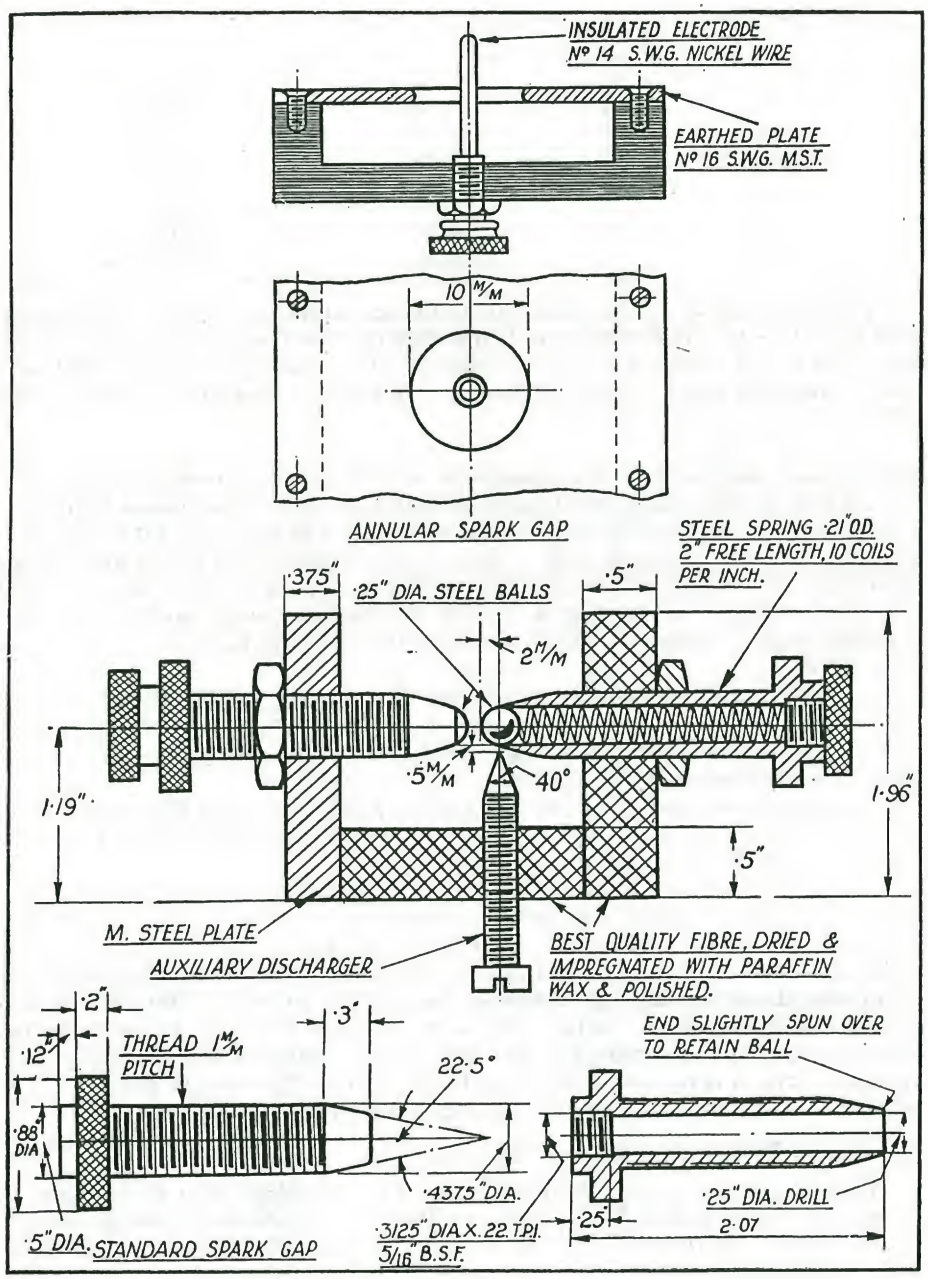
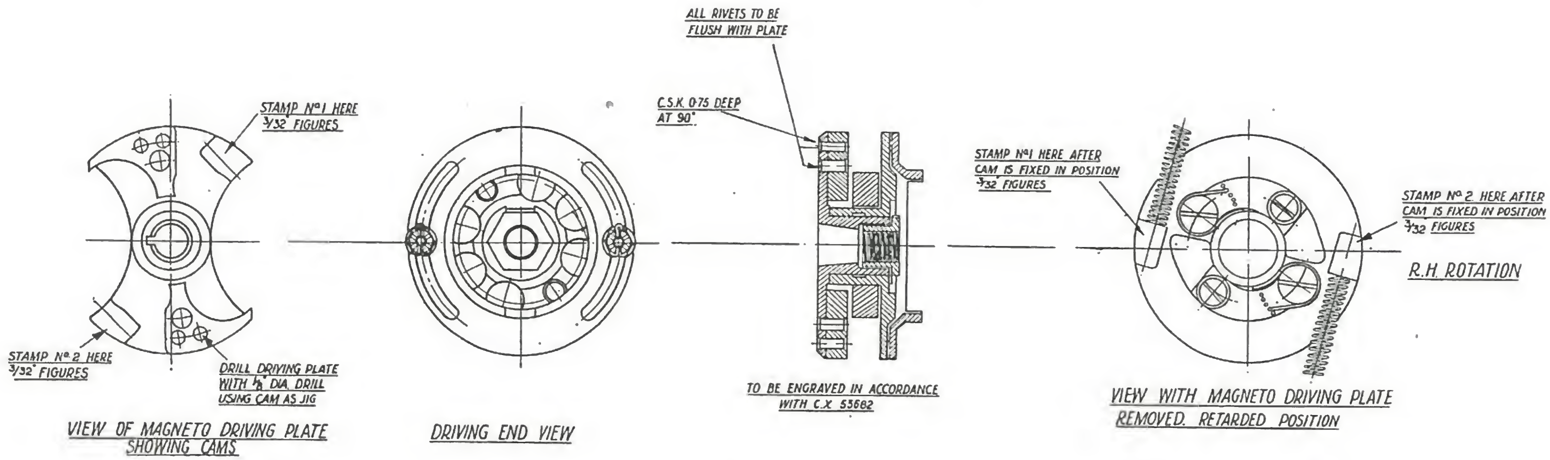


Fig. 83

drilled to hold the coil springs. These springs, together with the cams, determine the characteristics of the device. As the speed increases the weights tend to move outwards by centrifugal force, and as they move



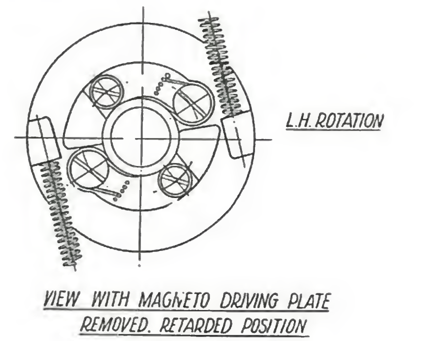


FIG. 84. AUTOMATIC ADVANCE AND RETARD COUPLING. MAIN ASSEMBLY

Setting of Cam. 1. Locate cam approx. by outer profile of both cam and magneto plate and lightly rivet over large rivet.

2. Assemble with driving plate and press plates radially apart until rollers are resting on centre boss, when there should be no movement between roller and cam. If there is movement, cams should be lightly tapped to take this up, care being taken to so adjust cams that the distance between spring blocks at periphery of plates is within the limits, minimum 25 mm., maximum 26 mm., 35° movement.

3. When requirements of (2) are fulfilled, magneto plate can then be drilled for riveting, using cams as jigs. Finally rivet securely all rivets.

on the cam from the magneto plate, they displace this plate in relation to the driving member, thus automatically advancing the magneto timing relative to the engine timing.

The degrees range of the device is determined by the distance between the spring bosses in the free position. As soon as the bosses come together, the spark ceases to advance and the device then operates for any higher speeds as a solid coupling.

Bonding

On aircraft of wooden or composite construction and, to a less degree, on aircraft of all metal construction, it is necessary to ensure that all metal parts, components, equipment, etc., are electrically connected together. This may be accomplished by the installation of a special system of bare copper wires, or by other approved means. Vibratory contact between adjacent masses of metal must be specially guarded against. The object of bonding is twofold, viz.: (*a*) as a precaution against fire, by avoiding the possibility of sparking between adjacent metallic masses, due to electrical discharge caused by flying through clouds or electrified atmosphere, and (*b*) as a means of maintaining the electrical capacity of the aircraft constant, and so avoiding the fading of wireless signals, as any variation in the natural capacity of the aircraft will affect the tuning of the wireless apparatus on board.

The full official requirements in regard to bonding are published in Air Ministry Specification G.E.125, which has been reproduced in full in the *Handbook of Aeronautics*,* and to which further reference should be made. but some notes on this subject appear on page 174 *et seq*.

* Published by Pitman.

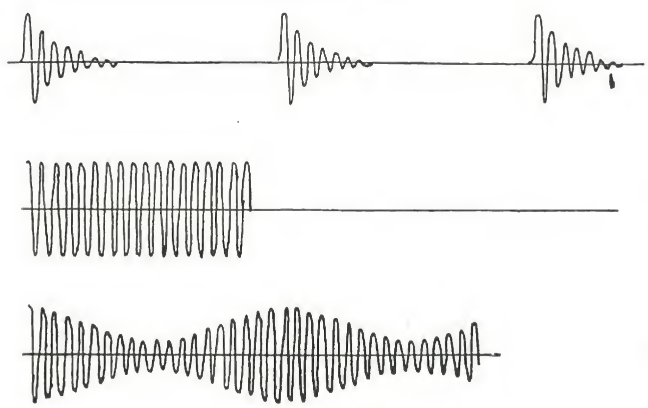
CHAPTER VI

WIRELESS EQUIPMENT*

WIRELESS signalling is carried out by means of aether waves radiated from a transmitting station, and the form of wave may be divided into two fundamental types, viz.—

(*a*) The wave radiated from a "spark" transmitter, and known as a spark or damped wave.

(*b*) The wave radiated from a continuous wave transmitter, and known as a continuous or undamped wave.



(*a*) Damped wave.

(*b*) Undamped wave.

(*c*) Modulated wave.

FIG. 85

Damped waves consist of successive wave trains in which the amplitude of the oscillations, after reaching a maximum, decline gradually to a minimum.

Signalling by means of damped waves can only be carried out by the use of the Morse or similar code, where letters and figures are represented by various combinations of long and short emissions of energy. Even the dot signal in this case will consist of a large series of separate damped oscillations. If the transmitting key is held down by the operator, a continuous noise will be heard in the telephones at the receiving end. Damped wave transmission is entirely unsuitable for telephonic communications, and its use on aircraft has now been abandoned.

Continuous waves are those which, after reaching the steady state, are periodic, i.e. the successive oscillations are identical. In the absence of some modifying influence, a transmitting station cannot communicate by Morse code on continuous waves, since no dots and dashes can be produced at the receiving end. The depression of the transmitting key will produce a simple click in the telephone receivers, and another click will be produced when the key is lifted, but there will be silence between the clicks, however long the key is held depressed, since the diaphragm of the telephone receiver cannot respond to the high frequency of oscillations of the continuous wave transmitter. In order that continuous waves

* Extracts from *A.P.* 1903, published by H.M.S.O., have been made with the kind permission of the Controller.

may be usefully employed they must be modulated in one of the following ways—

(*a*) By varying the amplitude, or frequency, by the keying operation, in telegraphic transmission. (Usually known as C.W.)

(*b*) By varying the amplitude, or frequency, in a periodic manner, at an audible frequency, and key controlled for the purpose of telegraphic transmission. (Usually known as I.C.W. or Tonic Train.)

(*c*) By varying the amplitude, or frequency, according to the characteristic vibrations of speech. (Usually known as Radio Telephony or R/T.)

The variation of frequency of C.W. transmissions may be accomplished at the sending station, by interrupting the aerial current at intervals corresponding to an audible frequency. A device for obtaining this is called a "tone sender." Another method of obtaining the desired result, is by interrupting the current in the detector circuit at the receiving station at audible frequency. An arrangement for doing this is called a "ticker," and is generally either an arrangement for breaking and making the circuit, or altering the capacity, inductance, or coupling, by breaking or making an additional circuit, or rotating a closed coil near one of the coils in circuit.

The normal method now adopted, however, is by loosely coupling to the detector circuit of the receiver a separate circuit known as the heterodyne circuit. This consists of an inductance and capacity in parallel, in which a continuous high frequency oscillation of very low amplitude is maintained by some suitable device—usually a valve. The frequency of the heterodyne circuit is made variable, between very wide limits, by adjustment of the condenser. When there is no incoming signal, the frequency of the heterodyne circuit is so high as to be inaudible, and no sound is heard in the telephones. When a continuous wave strikes the aerial, two voltages will be acting on the detector, one at the frequency of the incoming wave, to which the aerial and secondary circuits are tuned, and one at the frequency of the heterodyne circuit, which is coupled to the detector circuit. Unless these two waves are of exactly the same frequency they will not rise and fall in time with one another, but will get into step and out of step alternately. When they are in step there will be a maximum of voltage, since the two voltages are acting in the same direction. When they are out of step there will be a minimum of voltage, since the two voltages are acting in opposition to each other.

Thus, the interaction of the two waves gives rise to a "beat" voltage being applied to the detector, and the frequency of these beats of voltage is equal to the difference of the frequencies of the two component waves, and the rectified current through the telephones will rise and fall at this beat frequency, giving a corresponding note. The great advantage of the heterodyne system of reception is that the note is absolutely under the control of the receiving operator. By a slight variation of the heterodyne condenser he can adjust the note in his telephone to any pitch that suits his hearing, and it is thus very easy to get over interference by over-reading. When working on short waves very great accuracy in operation is required, but on long waves very great latitude in operation is possible.

The variation of amplitude of a continuous wave transmission may be accomplished at the sending station, and enables communication to be carried on with a receiving station which is not equipped with a heterodyne receiver. A continuous wave transmission which is broken up or varied in this manner is known as a tonic train, or interrupted continuous wave. When a steady voltage, as from a battery, is applied to the anode of a transmitting valve, a high frequency oscillation of constant amplitude is

generated in the aerial. If, then, an alternating voltage is applied to the transmitting valve, a high frequency oscillation will be generated whose amplitude will vary at alternating frequency.

The resulting condition of affairs is illustrated below. Whenever the anode is positive to the filament, an oscillation is set up in the aerial, which rises quickly from zero to a maximum, and dies away again as the anode voltage falls. During the negative half cycles of applied voltage, the valve ceases to maintain the aerial oscillation, which consequently dies away. We thus get a succession of tonic trains, one for each cycle of the A.C. supply, and these, when applied to the detector of the receiver, will give rise to a note in the telephones, without requiring a heterodyne. The note given is a pure one, whose pitch corresponds with that of the frequency of the alternating supply.

We have dealt with the telegraphic methods of communication by means of continuous waves, and there remains only the telephonic method.

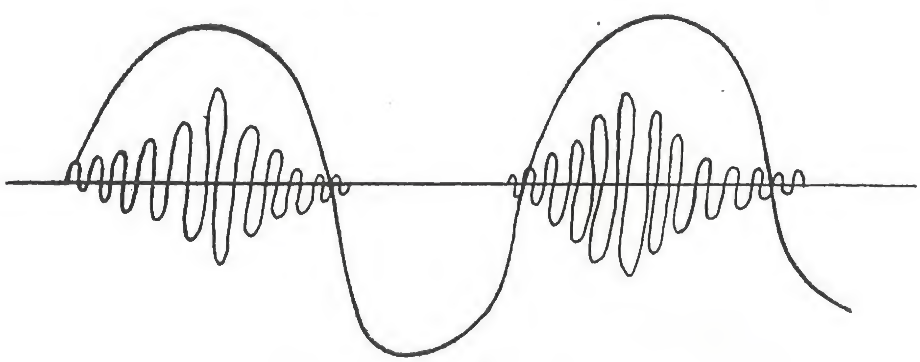


FIG. 86

In this system, also, the sending station generates and radiates a continuous wave emission which, as we have already explained, has a natural frequency much too high to be received by telephones in conjunction with an ordinary receiver. For the purposes of telegraphic communication we have shown how this emission of energy may be modulated, at either the sending or receiving end, to render the signals audible. For telephonic communication the continuous wave emission (carrier wave) is modulated at the sending end, by having impressed upon it audio frequency waves, produced by the effects of speech, music, etc., on a microphone, included in the transmitter circuit. For the reception of such transmissions a plain rectifying receiver only is permissible. The use of a heterodyne receiver of the type used for C.W. telegraphy would result only in the production of the note of the carrier wave over the speech. The range of communication by radio telephony is considerably less than with radio telegraphy, assuming transmitters, receivers, and other conditions to be otherwise equal.

Continuous wave communication is much more efficient than spark, or damped, wave communication, and much greater selectivity is obtainable, but on the other hand more apparatus, and of a more delicate nature, is required for its reception than is necessary for the reception of "spark waves."

No definite range can be laid down for any wireless transmitter. Generally, the range is governed by—

(*a*) Type of aerial used.
(*b*) Amount of power used in transmitting.
(*c*) The aerial of the receiving station.

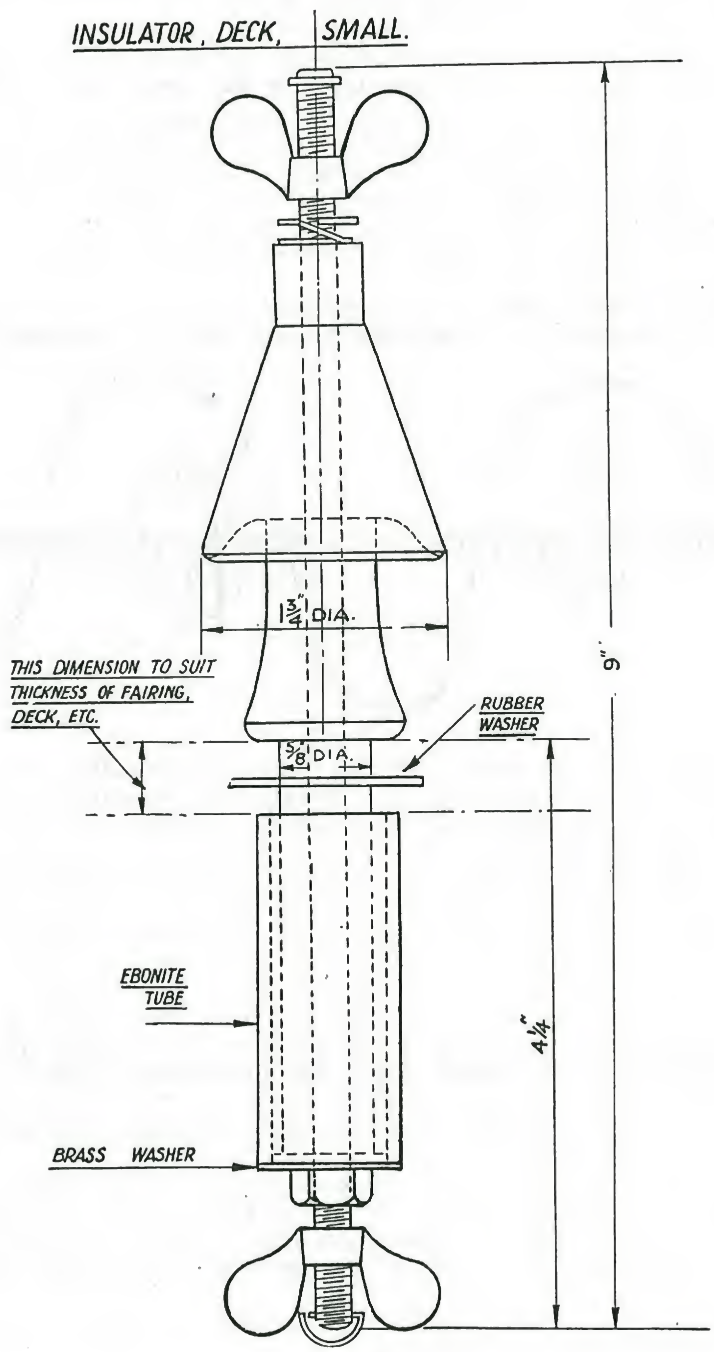


FIG. 87
(R.A.F. Official, Crown Copyright Reserved)

(*d*) The skill of the receiving operator.
(*e*) The efficiency of the receiving set.

The range of a transmitter used in the air is greater than that of the same transmitter used on the ground, but will vary with the type of aircraft and aircraft aerial, the receiver being the same in each case. Generally, the range of a transmitter is increased when working over water or very flat country, and decreased when working over hilly or heavily wooded country. In certain areas the absorption of aether waves is very marked, and causes a decrease in the strength of the signals received in these areas. There are also occasions when there is a marked decrease of signal strength due to "fading" effect, and although the causes of this "fading" effect are not fully understood, it may occur in any locality when working over long ranges.

An *aerial*, in one form or another, is an essential part of a wireless installation, both for transmission and for reception, and the aerial used on an aircraft may be of either the fixed or trailing variety. An aerial is a conductor, or system of conductors, usually open at one end and connected to a wireless transmitting or receiving instrument at the other end. The conductor used may be either covered or uncovered wire, but should not be made of magnetic materials (i.e. iron and steel). Copper or bronze wire is the most suitable. The conductors of the aerial must be very effectively insulated from the aircraft structure, and from any bulkhead or partition through or near which they may pass, before reaching the wireless set (Fig. 87). Porcelain is the most suitable material for insulation.

The normal aircraft type of aerial consists of a single wire varying in length from 150 ft. to 350 ft. This aerial consists of a number of strands to give it flexibility and strength, and is wound on a small winch or reel fitted into the aircraft, so that a part or the whole of the wire may be let out into the air through an insulated fairlead. When communication is carried out on one definite frequency (wave-length) it is desirable that when the whole of the wire is let out, the length of aerial shall be suitable for that frequency (wave-length). The end of the aerial wire is weighted to ensure that the wire is carried clear of the aircraft and to enable it to take up a suitable position in the air. The weight used for this purpose may be in one piece, weighing approximately 1 lb., or may be in the form of a number of smaller weights, weighing approximately 2 oz. or 3 oz. each, and spaced a few inches apart at the end of the aerial wire. Under normal conditions of flight the aerial takes up a position in the air as shown in Fig. 88.

This shape of aerial is directive, that is, it does not radiate equally in all directions. The only parts of the aerial which may be said to be good non-directive radiators are those parts which take up a vertical position in the air, i.e. the "weight" end and the aircraft end, but these represent a comparatively small part of the total aerial. The aerial shown in the above figure is directive fore and aft, that is, the signals will be strongest within its range in front or behind the aircraft; directly on each side the signals will be weakest.

In measuring the wire for a new trailing aerial, allowance must be made for the stretch of the aerial in the air, or the wire must be thoroughly stretched before measurement. The amount of stretch will vary with the type of wire used and the length of the aerial. A 200 ft. aerial of 7/25 gauge wire will stretch as much as 3 ft. to 5 ft.

An aerial should occasionally be run out from an aircraft on the ground, and the full length of wire inspected. If it is badly kinked, or shows signs of fraying, a new aerial should be substituted immediately. It is particularly necessary to examine the wire at the point where the weight is joined

to it. It is a good plan to fix the weight or weights on to a short section, say 2 ft. or 3 ft., of flexible steel wire, which in its turn is securely fixed to the end of the aerial wire.

A *fixed aircraft aerial*, that is, an aerial or aerial system which does not trail from the aircraft in flight, consists of a system of aerial wires fixed to the aircraft and insulated from it. This form of aerial is at present generally used in connection with short-wave telephony. Speech is possible between aircraft in any direction over a range of at least 2 miles,

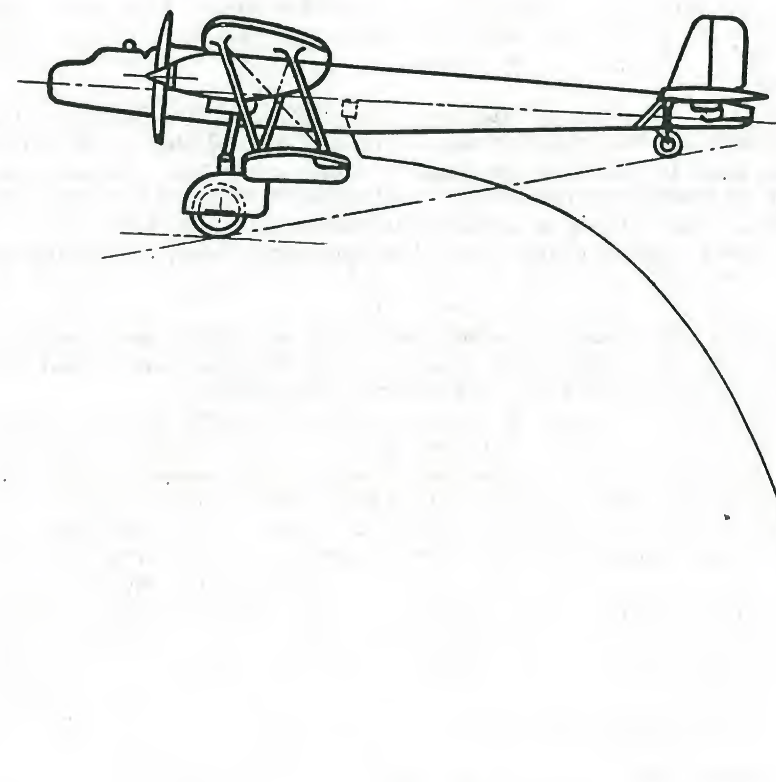


FIG. 88

and from the air to the ground up to 10 miles, but these are very arbitrary figures, and depend largely on the type of wireless set and the power used.

These aerials usually consist of wires stretched, one on each side of the aircraft, between wing tip and rudder post, with lead-in wires from the centre of each to a suitably placed deck insulator on the aircraft, and thus form a double T aerial. At wing tips and rudder post the aerial wires terminate in insulators, which are connected to the fixed attachments on the aircraft by means of a short length—twelve to fifteen inches—of rubber shock absorber cord, which keep the aerial wires taut whilst insulating them, both electrically from "earth," and mechanically from vibration, etc. The construction of a typical form of insulator is shown in Fig. 89.

The aerial wire, at its point of entry into the insulator, should be frequently inspected, as it is here that it is most likely to fray or break. Special precautions are necessary at the points of attachment to the tail to ensure that, should an aerial wire break in flight, and be blown back into the tail

structure, there will be no danger of it interfering with the free movement of rudder(s) and elevator(s).

A wireless transmitting set intended for use in aircraft requires official approval, both in respect of design and construction, before it is installed in the aircraft. Similar approval is also required in respect of the method of installation in the aircraft of the various components of the set, such as generator, batteries, aerial winch, transmitting unit, etc. In each case the main essentials necessary to obtain such approval are freedom from fire risks and freedom from weakening the structure of the aircraft, i.e. the object in view is to ensure that the airworthiness of the aeroplane is

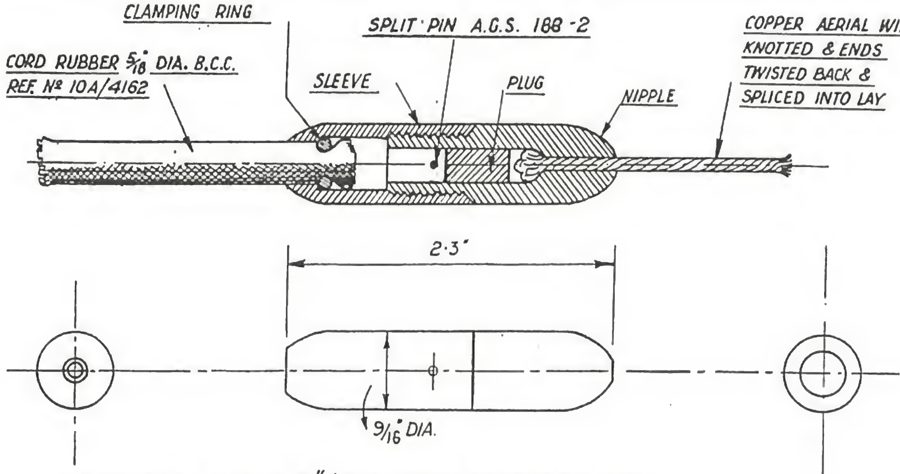


FIG. 89

(R.A.F. Official, Crown Copyright Reserved)

in no way impaired by the proposed installation. Some leading particulars of the principal sets manufactured for aircraft use are appended.

1. Marconi Type A.D. 41/42 Medium Wave Aircraft Telegraph-Telephone Set (Fig. 90)

The type A.D. 41/42 equipment in its full power edition has been specially designed for use on the larger types of civil, military, and naval aircraft where it is possible to carry a transmitter of adequate power to give the extended working ranges required by reason of the increased operational ranges of these aircraft, and when a supply of electrical energy is required for lighting and other services in addition to wireless. A reduced power edition is available for medium size civil and military aircraft.

The use of medium waves renders it particularly suitable for use on commercial aircraft which, by international regulations, are bound to use wave-lengths between 826 and 923 metres.

The most important features of the set may be briefly summarized as follows—

(1) The independent "drive" system has been incorporated in the transmitter, thus ensuring constancy of wave-length within narrow limits.

(2) The dial of the variable condenser controlling the drive circuit is calibrated in metres, which permits the rapid adjustment of the transmitter to any desired wave-length within the limits of the set without the use of a wave-meter.

(3) The use of the direct current grid control method of modulation by means of which the modulator valve acts as a variable grid leak in the grid circuit of the magnifier valve, ensuring full deep modulation.

(4) Provision can be made for quick wave selection.

(5) Telegraphy by *continuous* and *interrupted continuous waves* and *telephony.*

Both the transmitter and receiver are designed to cover a wave range of 500–1,000 metres (600–300 kcs.).

Quick wave selection of five pre-determined wave-lengths within a 120-metre band located between the limits of 800 to 1,000 metres can be provided.

The ranges obtainable with the type A.D. 41/42 equipment depend to a certain extent upon the type of aircraft in which it is fitted and on the characteristics of the ground station with which it has to work. Assuming satisfactory installation of the equipment in the aircraft and an efficient ground station of modern design, the maximum range obtainable will be—

	Full Power Transmitter	*Reduced Power Transmitter*
Air to ground Telephony .	400 km. (250 miles)	320 km. (200 miles)
Air to ground I.C.W. Telegraphy	480 km. (300 miles)	400 km. (250 miles)
Air to ground C.W. Telegraphy . . .	800 km. (500 miles)	600 km. (375 miles)

The above ranges are obtainable with a "trailing" aerial of the usual type fitted to the aircraft.

Alternative power supply equipments can be supplied to operate the transmitter at either full or reduced power; when operated at full power, the power to the anodes of the magnifier valves is approximately 170 watts, while, at reduced power, it is approximately 100 watts.

The power for the transmitter and receiver together with additional low-tension output is normally derived from a wind-driven generator fitted with a constant speed windmill. The generator provides high-tension for the anode circuits of the transmitting and receiving valves and an adequate low-tension output which charges a 12-volt accumulator. This accumulator forms the main battery of the aircraft which provides current for wireless, lighting, heating, and other purposes. This system has the advantage of avoiding the carriage of two generators, thus effecting a considerable overall reduction in the weight of the equipment necessary to provide the required services. Alternative power supplies are available to suit cases where the aircraft is already equipped with an electrical installation of sufficient capacity to deal with the wireless equipment or where the provision of lighting, etc., is not required.

The transmitter and receiver form two separate units which can either be mounted together or suspended separately to suit the particular aircraft in which the set is to be installed. Each unit can be provided with remote control apparatus.

The operation of changing from "send" to "receive," also tuning adjustment of the receiver and wave selection in the transmitter can be performed by remote control. Selection of continuous wave, interrupted continuous wave or telephone transmission by remote control can also be provided if required.

Intercommunication apparatus can be supplied enabling either the operator/observer or the pilot to use the set and also affording a means of communication between them.

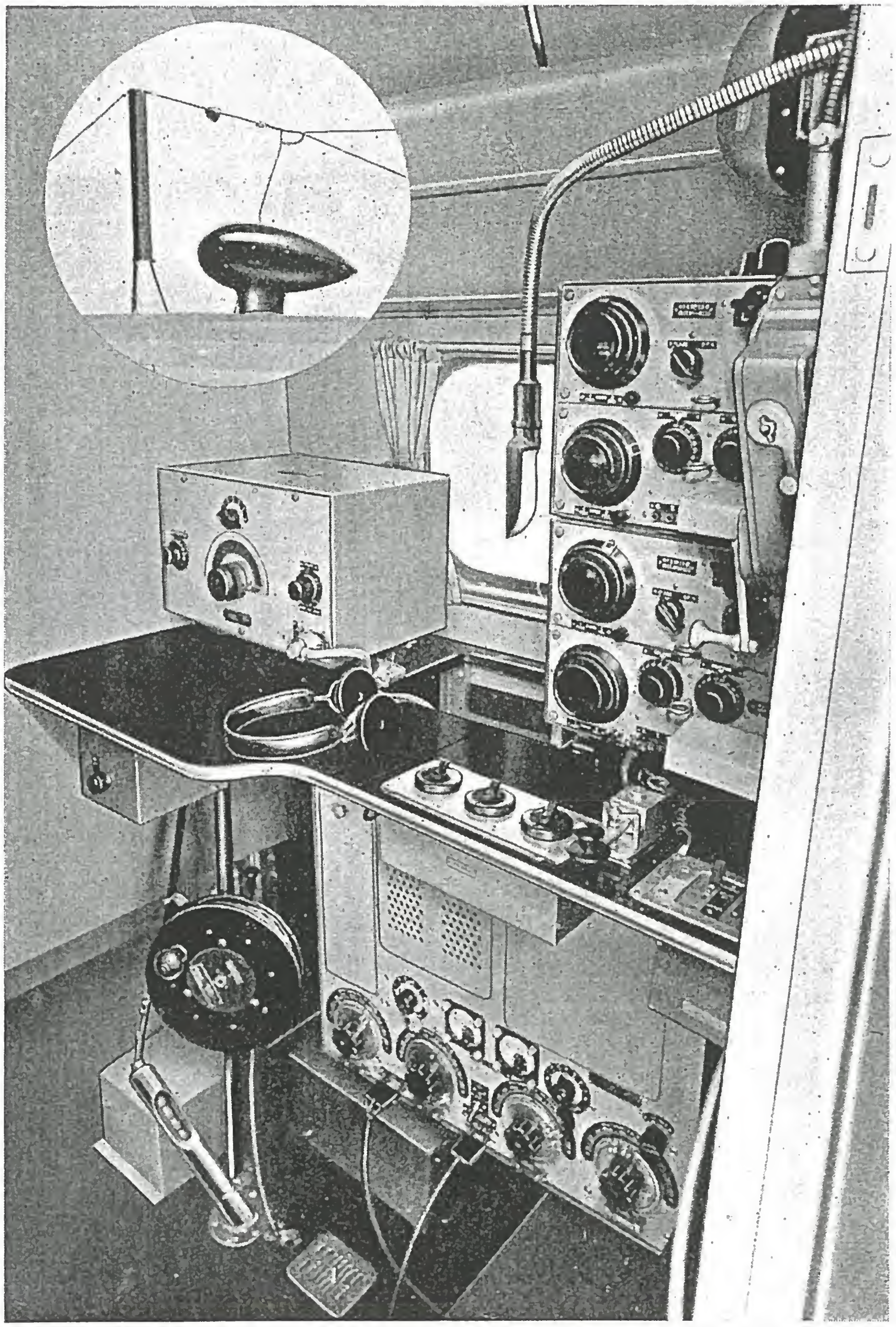


FIG. 90. MARCONI TYPE A.D. 67A/84/5062D AIRCRAFT WIRELESS EQUIPMENT INSTALLED IN A BRITISH AIRWAYS LOCKHEED "14" AIRCRAFT

Left: Type A.D.84 Receiver. *Right:* Two Type A.D.5062D D.F. Receivers and *below* Type A.D.67*a* Transmitter. *Inset:* Fixed aerial support and streamlined casing for D.F. loop

The type A.D. 41/42 equipment, being designed for operation on medium wave-lengths, necessitates the use of a "trailing" type of aerial for all normal purposes. Where desired, a fixed aerial can also be fitted which enables short range communications to be obtained and permits, for example, of "close formation" flying to be carried out in military service.

Where required for emergency working of the wireless equipment, a light 1 h.p. petrol engine can be provided for driving the wind-driven generator when the aircraft is at rest. The generator can either be dismounted from its normal mounting and direct coupled to the engine, or it may be left in its normal position and coupled to the engine by means of a flexible shaft. This arrangement provides communication in the event of a forced landing and also can be used for testing the equipment on the ground. Emergency working for short periods can also be carried out by motoring the wind-driven generator from the accumulator, after removing the windmill.

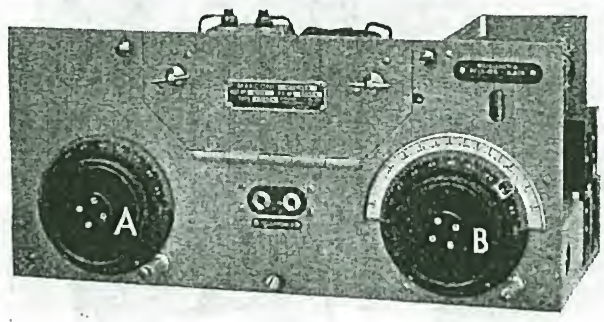


FIG. 91. RECEIVER, TYPE A.D.42
A = Reaction control. *B* = Tuning control.

Direction-finding facilities on the Marconi-Robinson principle can be provided for by the addition of a fixed or rotatable frame aerial and a small light attachment to the aircraft receiver.

A 12-volt accumulator of the unspillable type is normally supplied, the capacity of which is varied to suit the electrical requirements of the aircraft to be equipped.

The switchboard, supplied for combined wireless and lighting, comprises the necessary regulators, switches, fuses, meter, and cut-outs for controlling the low-tension charging.

The following table indicates the types, number, and electrical characteristics of the valves used in the set—

Type	No.	Used for	Filament		Approximate Anode Volts
			Supply Volts	Amperes (Total)	
Det. 1	3	Transmitter	12·0	4·0	1,000/1,200
*M.L. 4	1	Transmitter			Nil
S. 410	1	Receiver	12·0	1·9	120
H.L. 410	1	Receiver			
*M.P.T. 4	1	Receiver			

* These two valves are indirectly heated, and to avoid time-lag when changing over from Transmit to Receive and *vice versa*, the modulator and all the receiving valve filaments are kept heated on both transmit and receive while being extinguished on the *off* position. The total filament current consumption on Transmit is, therefore, 5·9 amperes and on Receive is 3·9 amperes at 12 volts.

The weight of the complete transmitting and receiving equipment depends to a certain extent upon lengths of inter-connecting cables. Without any of the optional items, such as intercommunication apparatus, emergency power supplies, etc., the weights of the equipment are approximately as follows—

Equipment	Combined Wireless and Electrical Services	Wireless Equipment only for Use with Existing Electrical Equipment	Wireless Equipment and Rotary Transformers
Full power transmitter . . .	145 lb. (66 kg.)	—	—
Reduced power transmitter . .	120 lb. (54·5 kg.)	75 lb. (34 kg.)	97 lb. (44 kg.)

Additional weight for—	
Intercommunication gear	8 lb. (3·65 kg.)
Fixed aerial supplies	7·5 lb. (3·4 kg.)
Emergency equipment	57 lb. (26 kg.)
Remote control	5 lb. (2·3 kg.)
Remote control for wave selector . . .	2 lb. (0·9 kg.)

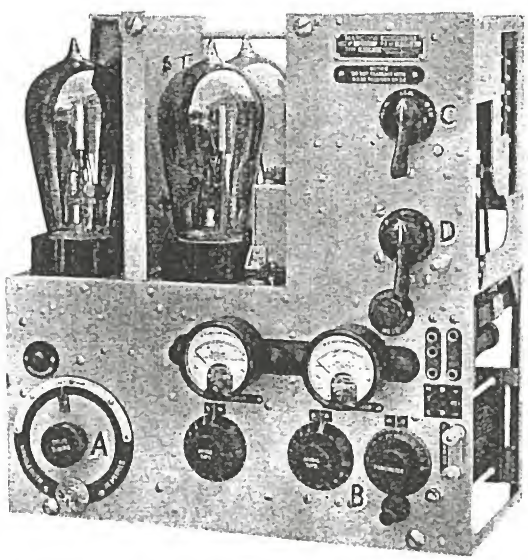


FIG. 92. TRANSMITTER, TYPE A.D.41

A = Drive tuning condenser. C = Telegraph-telephone change-over switch.
B = Aerial tuning controls. D = Send-receive change-over switch.

Note. If the aircraft is already fitted with a 12-volt heating, lighting, and charging equipment, which will also provide the extra wireless load (i.e. approximately 250 watts) rotary transformers can be supplied instead of the wind-driven generator.

The above schedule is then modified as follows—

One Rotary Transformer . .	For transmitter: 12 volts 19 amperes input; 1,000 volts 150 milliamperes output.
One anode converter* . . .	For receiver: 12 volts 2 amperes input; 120 volts 30 milliamperes output.
One generator with constant speed Windmill	Deleted.
One switchboard	Deleted.
One accumulator (12 volt) . .	Deleted.
Code word	IGUFZ.

* A 120-volt H.T. dry battery can be supplied instead of the anode converter if desired.

2. Marconi Medium Wave Aircraft Wireless Equipment, Type A.D. 49/50

The type A.D. 49/50 equipment has been specially designed for use on the smaller types of civil, military and naval aircraft where restricted space or service requirements preclude the use of a higher power equipment.

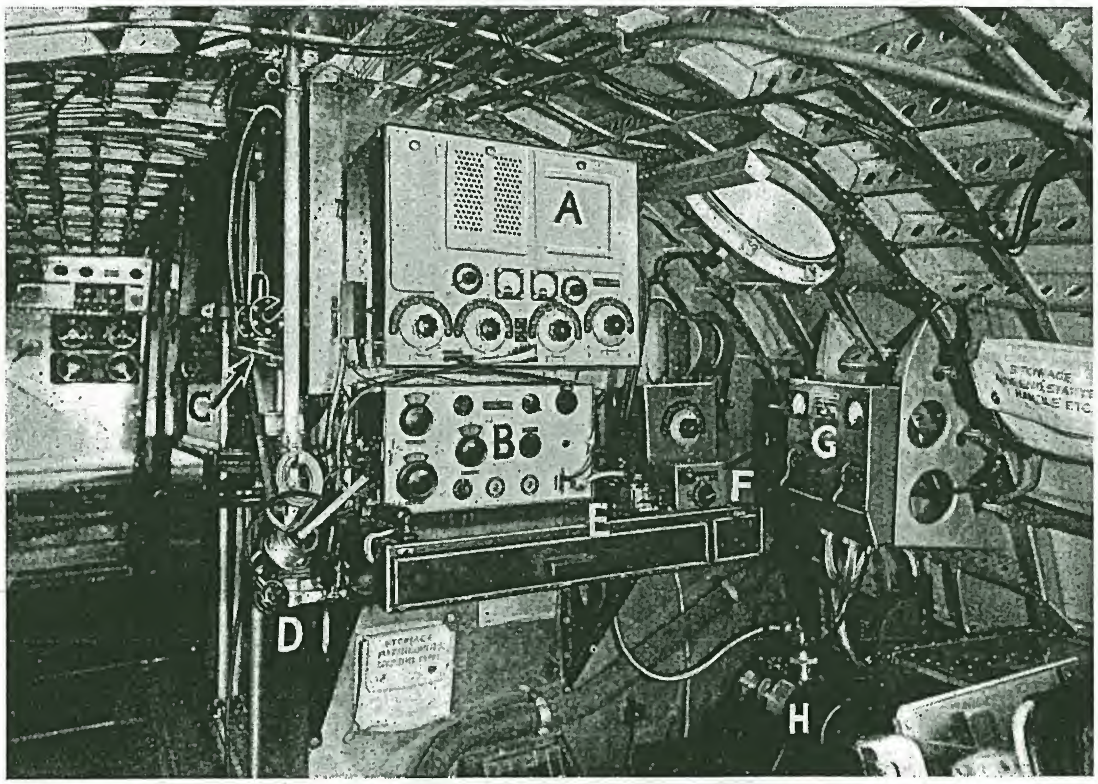


FIG. 93. MARCONI TYPE A.D. 67/6872 TRANSMITTING-RECEIVING AND DIRECTION-FINDING EQUIPMENT INSTALLED IN AN IMPERIAL AIRWAYS FLYING BOAT

A = Type A.D.67 Transmitter.
B = Type A.D.6872 Receiver.
C = Rotatable frame aerial for direction finding.
D = Microphone and telephones.
E = Manipulating key.
F = Hand reversing switch for "D.F." and "Homing."
G = Main power control unit.
H = H.T. power supply unit.

The use of medium waves renders it particularly suitable for use on commercial aircraft which, by international regulations, are bound to use wave-lengths between 826 and 923 metres.

The most important features of the set may be briefly summarized as follows—

(1) Both the transmitter and receiver are fitted with quick release shock-absorbers. After unplugging the connecting leads from a junction box, the transmitter and receiver can be easily removed for inspection purposes.

(2) The transmitter incorporates a special circuit with two multi-electrode valves connected in parallel which perform the functions of "drive" or master oscillator, power magnifier and modulator.

(3) The dial of the drive tuning condenser is calibrated in metres which

permits of rapid adjustment to any desired wave-length within the limits of the transmitter without the use of awave-meter.

(4) Provision can be made for quick wave selection within the wave-range of the transmitter by either direct or remote control.

(5) Telegraphy by *continuous* and *interrupted continuous waves* and *telephony*.

The transmitter is designed to cover a continuous wave-band of 600 to 1,000 metres (500–300 kcs.).

The receiver is designed to cover a continuous waveband of 600 to 1,550 metres (500–196 kcs.).

The ranges obtainable with the type A.D. 49/50 equipment depend to a certain extent upon the type of aircraft in which it is fitted and on the characteristics of the ground station with which it has to work. Assuming satisfactory installation of the equipment in the aircraft and an efficient ground station of modern design, the following ranges should be obtainable:

Air to ground	240–290 km.	(150–180 miles)
Air to ground I.C.W. Telegraphy	290–350 km.	(180–220 miles)
Air to ground C.W. Telegraphy	400–480 km.	(250–300 miles)

The maximum power rating of the transmitter is approximately 65 watts to the anode of the magnifier valve on C.W. and I.C.W. Telegraphy and approximately 45 watts on Telephony.

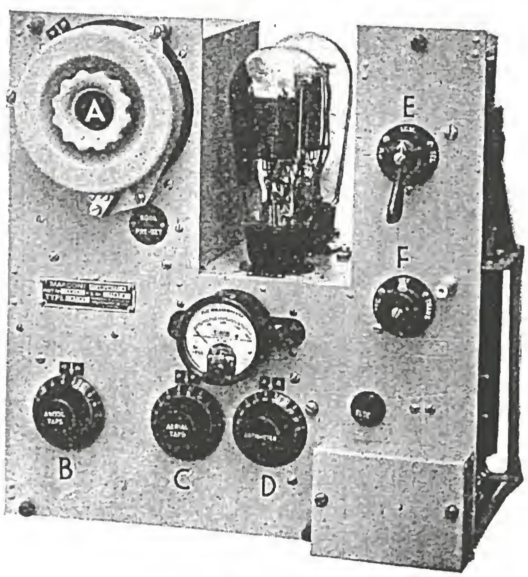


FIG. 94

Power for the transmitter and receiver can be derived from a double output wind-driven generator fitted with a constant speed windmill. The generator provides high-tension for the anodes and low-tension for the filaments of the transmitting and receiving valves. If combined wireless and electrical services are to be provided, a generator with a larger L.T. output for charging a 12-volt accumulator is supplied.

An alternative power supply in the form of a rotary transformer is available for use in aircraft already equipped with a 12-volt battery of sufficient capacity to deal with the wireless equipment.

The receiver is designed for installing near to and for direct operation by the pilot. The transmitter, when fitted with remote control, can be installed in any convenient position in the aircraft. Quick release shock-absorber fastenings can be fitted to the top, back or bottom of the instrument boxes, thereby considerably facilitating installation work.

The operation of the "send-receive" switch and of quick wave selection in the transmitter can be performed by remote control if desired. Selection of continuous wave, interrupted continuous wave or telephone transmission by remote control can be provided if required.

When remote control wave selection is fitted a pilot lamp at the pilot's

end of the control unit indicates the correct setting of the tuning condenser for the required wave-length.

The type A.D. 49/50 equipment being designed for operation on medium wave-lengths necessitates the use of a "trailing" type of aerial for all

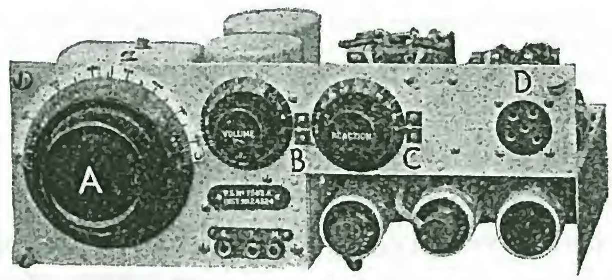


FIG. 95

normal purposes. Where desired, a fixed aerial can also be fitted which enables short range communications to be obtained and permits, for example, of "close formation" flying to be carried out in military services.

Facilities for direction finding by either the "homing" system or by taking D.F. bearings on ground transmitters can be provided by means of the addition of a frame aerial and a small amplifying attachment to the normal receiver.

The switchboard, supplied for combined wireless and lighting, comprises the necessary regulators, switches, fuses, meter and cut-outs for controlling the low-tension charging.

The following table indicates the types, number and electrical characteristics of the valves used in the set—

Type	No.	Used for	Filament		Approx. H.T. Volts
			Supply Volts	Amperes (Total)	
D.E.T. 8	2	Transmitter	12	2	800
*M.S. 4 B	2	Receiver	} 12	1·0	200
*M.H. 4	1	Receiver			

* These two valves are indirectly heated and in order to avoid time lag on changing from "Transmit" to "Receive" are kept heated during transmission and reception. The total filament current is 3 amperes on "Transmit" or "Receive."

The weight of the complete wireless equipment depends to a certain extent upon the length of the connecting cables, and the accessories provided. Without any optional items, the weight of the equipments are approximately as follows—

Power Supply	Wireless Equipment for Use where Lighting, etc., is not required	Combined Wireless and Electrical Services
Wind-driven generator	62 lb. (28 kg.)	*80 lb. (36·5 kg.)
Rotary transformer	*62 lb. (28 kg.)	

* Excluding 12-volt battery.

Additional weight for remote control (wave selector), 2 lb. (0·9 kg.)

3. The Plessey, Type A.C.44

This is a medium power equipment intended for use where telegraph or telephone communication is required on medium waves from 600 to 1,000 metres, and where remote operation and remotely operated wave-length changing is required. Normally four pre-set wave-lengths (600, 862, 900, and 930 metres) are provided on the transmitter, but these may be adjusted to suit requirements, and in special cases wavebands other than 600–1,000 can be provided. Receiver tuning is continuously variable

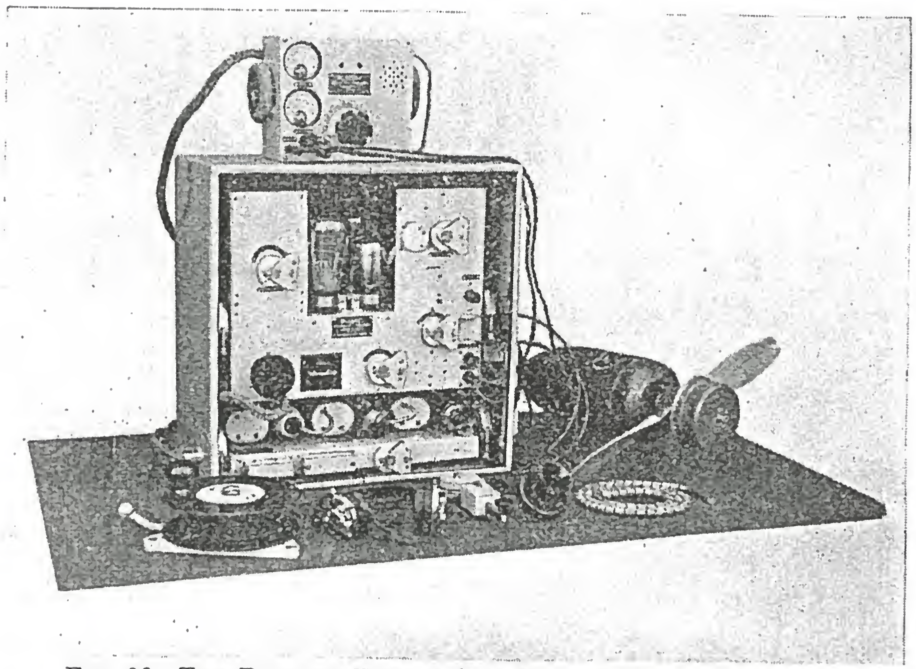


FIG. 96. THE PLESSEY TYPE A.C.44 MEDIUM RANGE EQUIPMENT

550–1,000 metres, but if required the receiver can be provided with a second waveband above or below the normal or on short waves.

The transmitter input is 160 watts H.T. at 600 volts, and 60 watts L.T. at 9 volts. The output power (aerial) is 36 watts (C.W. telegraphy), 18 watts (telephony), or 18 watts (I.C.W. telegraphy).

The transmitter employs a master oscillator for frequency control. This master oscillator drives two amplifier valves in parallel, the anodes of which are connected to the aerial circuit through a special coupling circuit which prevents overloading of the amplifiers should the aerial be lost or the aerial circuit detuned.

At the same time, a pre-set adjustment on the aerial loading coil enables the equipment to be readily adjusted in the case of aircraft having different aerial capacities, and this equipment can be used in aircraft having aerial capacities from 200–350 mmf. without any difficulty and without the need of tapped loading coils.

It should be noted that in the operation of this transmitter, when the aerial circuit is detuned, the D.C. to the anodes of the amplifier valves falls instead of rising, and that in tuning the transmitter the aerial tuning should be varied until the maximum plate current is obtained, and not the minimum.

Telephony and I.C.W. are obtained by means of a low-power modulation system giving approximately 70 per cent modulation.

RANGE

Telephony and I.C.W. Telegraphy . .	180 miles
C.W. Telegraphy	500 miles

These ranges are those which will be obtained under general conditions when working from aircraft to a modern airport. In particular parts of the world, ranges considerably in excess of these will be obtainable in some cases.

All the transmitter units are carried on a light weight aluminium framework, the master oscillator being entirely screened from the remainder of the circuit. All valves are mounted on a panel in the centre of the unit. The aerial tuning and coupling units are carried on the right-hand side of the valve panel, while the modulation and control circuits are contained at the bottom of the framework.

A main plug on the front of the transmitter carries the cables connecting the transmitter and receiver to the generator and other units. On removing this plug and releasing the rubber ring supports, the transmitter can instantly be withdrawn from the crate.

VALVES

Master Oscillator	Mullard T25 D
Amplifier	Mullard T25 D (two in parallel)
Modulator	Mullard 104V

The receiver is of the superheterodyne type, and is provided with automatic volume control and special circuits for the reception of C.W. telegraph signals. A total of four valves is employed, giving a maximum sensitivity of 35 microvolts with an output power sufficient for loud reception in two pairs of low-resistance telephones.

With an input of approximately 50 microvolts, the receiver will produce 0·75 watts of speech across the telephones.

The receiver tuning is performed electrically. No mechanical controls are employed, and hence all backlash and difficulty in tuning is obviated. No reaction control is provided and only one main control on the receiver is required, the automatic volume control keeping the level of received signals correct.

For the reception of C.W. telegraphy, a switch on the receiver brings into operation a local oscillator which provides the required beat note, and this beat note is maintained constant in amplitude by the automatic volume control, with the result that the aircraft may fly directly over a station transmitting C.W. telegraphy without loss of beat note and without interference due to key clicks.

The construction of the receiver is similar to that of the transmitter, and the rubber suspension system is also similar. The receiver is mounted in the crate below the transmitter so that the circuits are not affected by heat from the transmitter valves.

VALVES

Mullard FC 4	Mazda AC/HL/DD
Mazda AC/VP 1	Mazda AC/2PEN/DD

The transmitter and receiver are provided with metal bosses carrying flexible rubber rings which are held in special supports in a welded tubular steel crate. This crate is enclosed with detachable sides, provided with ventilation, and both the transmitter and receiver are therefore contained

in one unit floating on rubber and the crate can be bolted direct into the aircraft without further preparation.

The transmitter and receiver can be supplied in separate crates for installation in small aircraft.

The control unit is designed to be fitted near the pilot in the case of

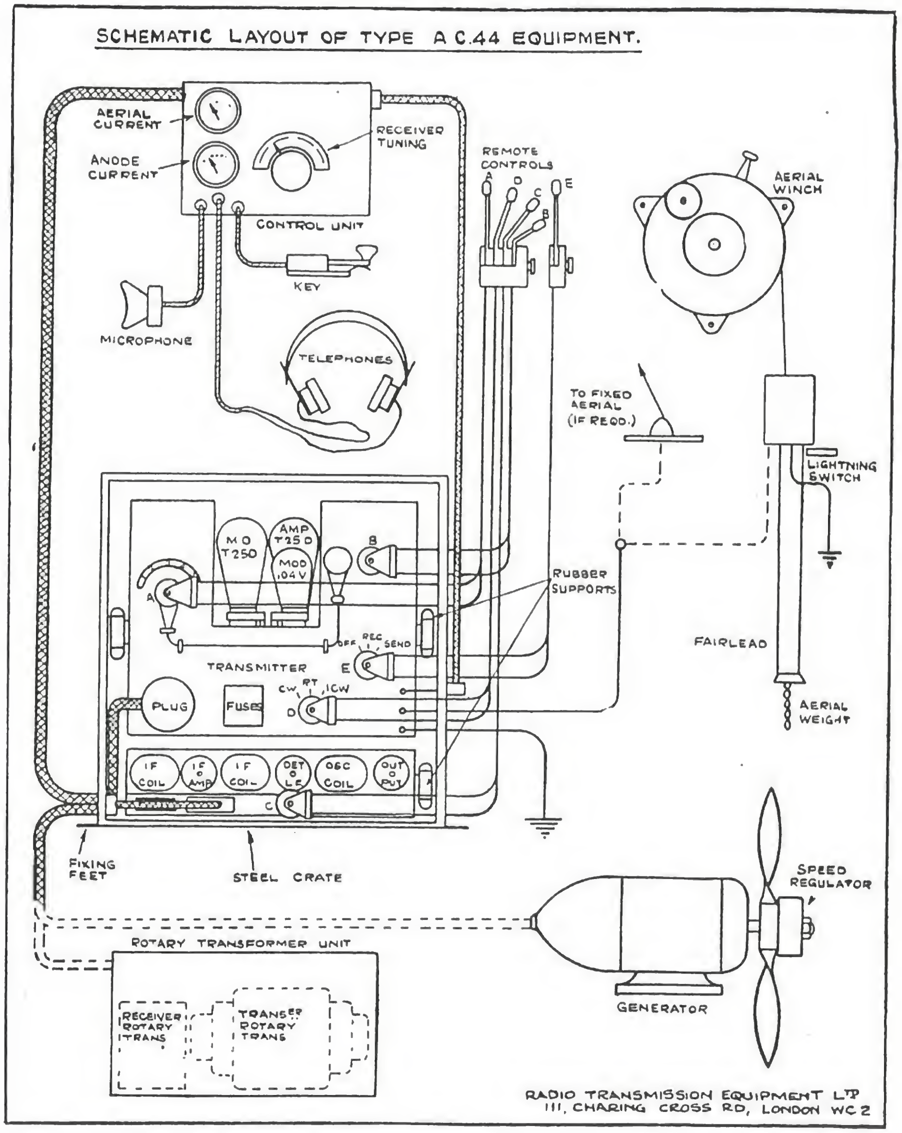


FIG. 97

the remotely operated installation, or near the operator where the apparatus is not remotely operated.

The unit contains—

One D.C. feed meter indicating the total current consumption of the equipment.

One aerial ammeter indicating the aerial current.

Three jacks for microphone, telephones, and key.

A special receiver tuning control with wave-length change switch where the receiver employs two wavebands.

As already stated, this receiver tuning control is performed electrically and is entirely free from backlash or other difficulties usually connected with the mechanical system of tuning. The control unit is connected to the transmitter unit by a cable carried in a braided sleeving provided with a metallic shield to prevent interference from external sources being picked up on the receiver.

The construction is similar to that of the other units. A light metal framework carries all the components and circuit and this is fitted with a removable front cover.

The control unit is supported on rubber rings in a similar manner to the transmitter and receiver, but it is not contained in a crate, the supports for the rubber rings in this case being fitted direct to the structure of the aircraft.

Two aerial systems may be used—

(1) Trailing aerial.

(2) Fixed aerial.

Communication on trailing aerial will usually be much better than on fixed aerial and much longer ranges will be obtained.

In very large aircraft good results may be obtained from the fixed aerial system, which is usually fitted between wing tips and tail of the machine.

Type A.C. 44B

This equipment is exactly similar to the type A.C.44, but, instead of the master oscillator being adjusted in steps, a continuously variable wave-length range between 550 and 1,000 metres is provided. It is primarily intended for installations not employing remote control.

A complete equipment comprises the following—

	Dimensions	Weight
Transmitter	14 in. × 7 in. × 11 in.	15 lb.
Receiver	14 in. × 7 in. × 3½ in.	4 lb.
Control unit	8¾ in. × 6½ in. × 2½ in.	4 lb. 2 oz.
Remote controls	——	1 lb. 8 oz.
Winch with aerial Wire and weight	6 in. dia.	6 lb. 12 oz.
Fairlead	according to installation	2 lb.
Microphone Telephones (1 pair and telegraph key)	——	1 lb. 8 oz.
Generator windmill and speed regulator	12 in. × 4½ in.	16 lb.
Cables	according to installation	2 lb.
Steel crate and cover	9 in. × 16·⅜ in. × 17 in.	7 lb. 6 oz.

Approx. total weight, Type A.C. 44 . . . . 60 lb. 4 oz.
Approx. total weight, Type A.C. 44B . . . . 54 lb.

4. Marconi Combined Medium Wave and Short Wave Aircraft Telegraph-Telephone Set—Type A.D.37a Transmitter, A.D.38a Receiver (Fig. 98)

The type A.D.37a/38a equipment has been approved by the British Air Ministry for fitting in British commercial aircraft, and is installed on the Imperial Airways aeroplanes flying on the England–South Africa air route.

The most important features of the set may be briefly summarized as follows—

(1) Separate high-frequency circuits are employed for the two transmitting wave-ranges, but by utilizing the same valves, modulator system, and other component parts in common, it has been possible to produce an extremely compact design.

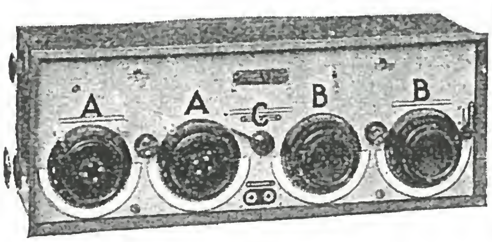
(2) The independent "drive" system has been incorporated in both the medium and short-wave circuits, thus ensuring constancy of wave-length within narrow limits.

(3) The dials of the variable condensers controlling the two drive circuits are calibrated in metres, which permits the rapid adjustment of the transmitter to any desired wave-length, within the limits of the set, without the use of a wave-meter.

(4) The use of the direct current grid control method of modulation, by means of which the modulator valve acts as a variable leak across the grid circuit of the magnifier valve.

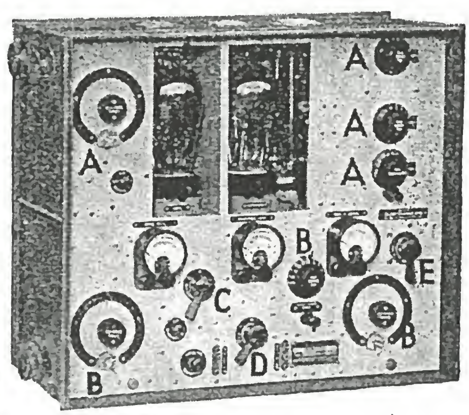
(5) Separate high-frequency circuits and a high-frequency amplifying valve are employed for the two receiving wave-ranges. The detector valve and the low-frequency magnifier valve are common to both wave-ranges.

The combined medium and short-wave transmitter forms a



Type A.D.38a Receiver

Transmitter
A = Medium wave controls.
B = Short wave controls.
C = Medium/short wave C.O. switch.



Type A.D.37a Transmitter

Receiver
A = Medium wave controls.
B = Short wave controls.
C = Medium/short wave C.O. switch.
D = C.W.-I.C.W.-telephone switch.
E = Send-receive switch.

Fig. 98

single unit in one box, and the receiver constitutes a second unit in a separate box of identical width and depth. The two instrument boxes can, therefore, be installed either separately or as one unit, according to the space available in the aircraft.

Direction finding facilities can be provided for by the addition of a small light attachment to the aircraft receiver.

The set provides for the transmission and reception of continuous wave, interrupted continuous wave, and telephone signals. The transmitter is provided with the independent drive method of frequency control.

The transmitter and receiver are continuously adjustable between the following limits—

Medium-wave range	500–1,000 metres
Short-wave range	40–80 metres

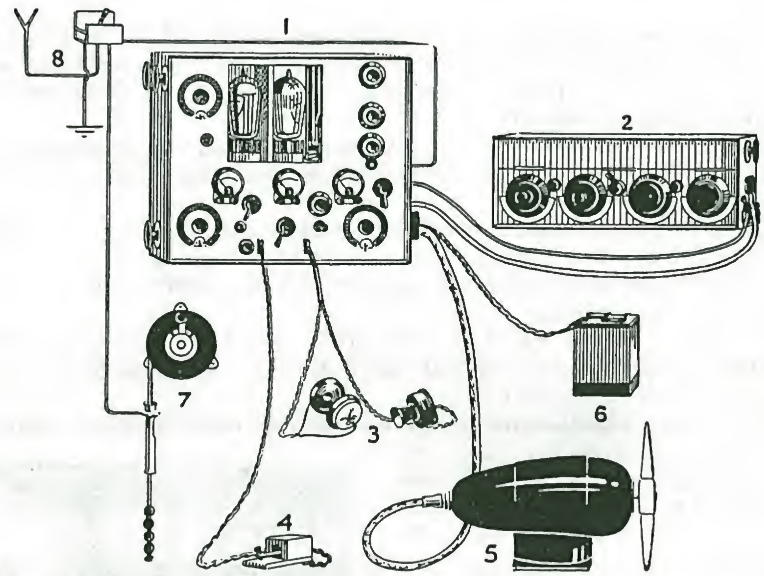


FIG. 99. KEY PLAN OF STANDARD EQUIPMENT FOR TYPE A.D.37A/A.D.38A AIRCRAFT SET

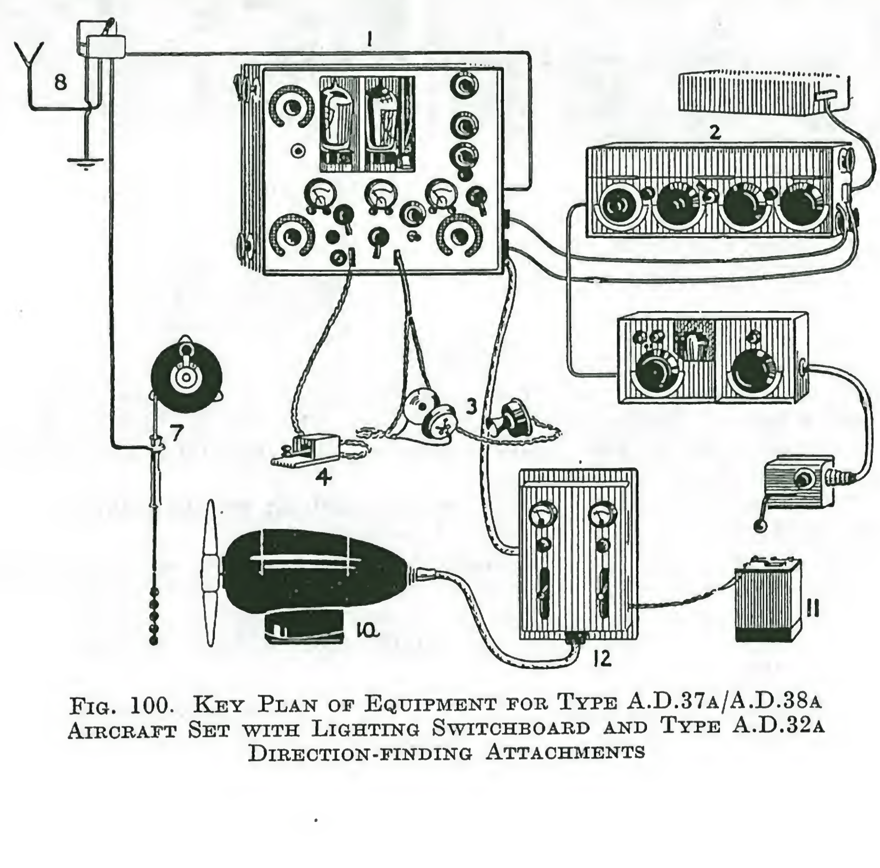


FIG. 100. KEY PLAN OF EQUIPMENT FOR TYPE A.D.37A/A.D.38A AIRCRAFT SET WITH LIGHTING SWITCHBOARD AND TYPE A.D.32A DIRECTION-FINDING ATTACHMENTS

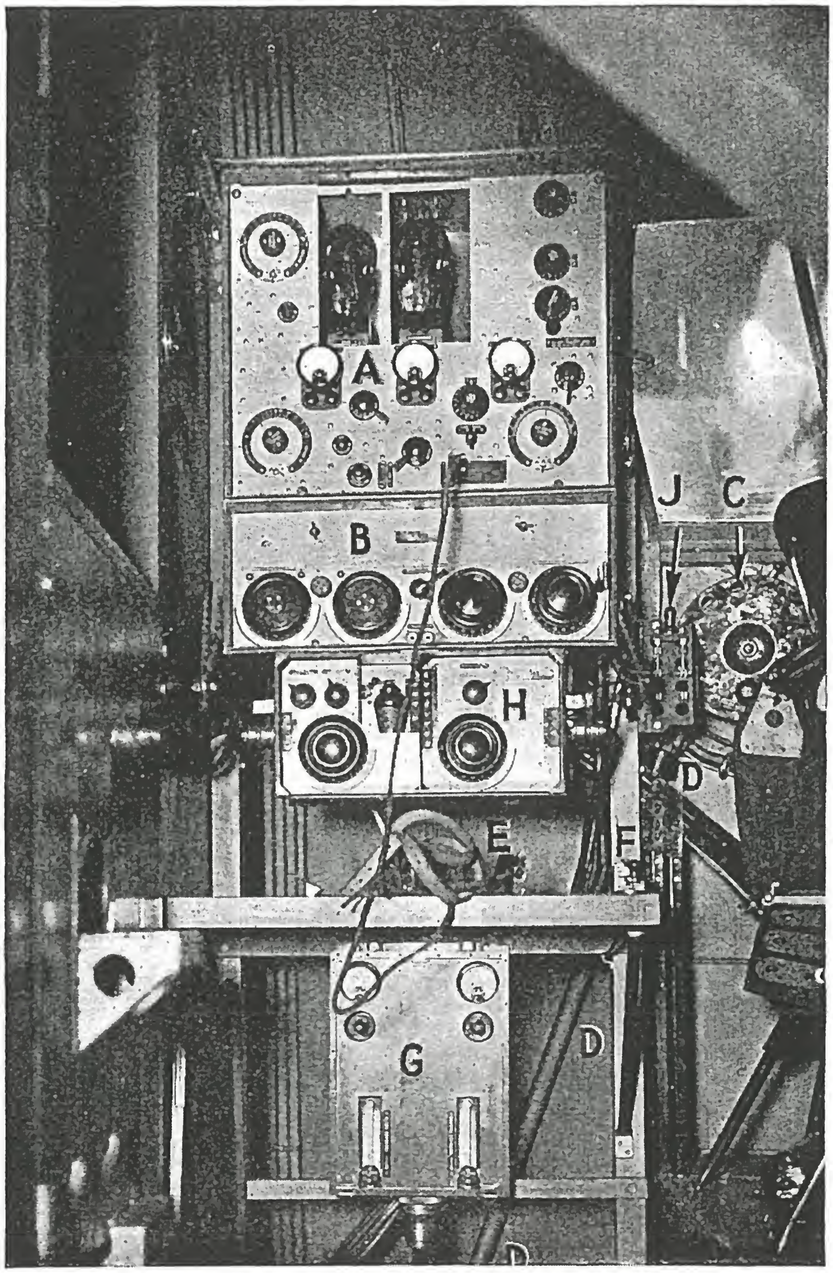


FIG. 101. MARCONI TYPE A.D.37A/A.D.38A AIRCRAFT SET AND THE TYPE A.D.32A DIRECTION-FINDER INSTALLED IN AN IMPERIAL AIRWAYS PASSENGER-CARRYING AEROPLANE

A = Transmitter.
B = Receiver.
C = Aerial winch.
D = Fairlead.
E = Microphone and telephones.
F = Manipulating key.
G = Combined wireless and lighting switchboard.
H = D.F. attachment.
J = Aerial change-over switch.

Additional plug-in-coils can be provided to extend the wave-range of the receiver from 40 to 150 metres.

Alternative power generators can be provided to operate the transmitter at either full or reduced power. When operated at full power, the input to the anodes of the magnifiers is approximately 170 watts on the medium wave-lengths and approximately 120 watts on the short wave-lengths. At reduced power the figures are approximately 100 watts and 70 watts respectively.

Assuming normal conditions and the use of a modern receiver at the aerodrome, the maximum ranges from aircraft to ground are approximately—

	Full Power	*Reduced Power*
C.W. Telegraphy . .	500 miles (800 km.)	380 miles (600 km.)
I.C.W. Telegraphy . .	300 miles (480 km.)	250 miles (400 km.)
Telephony . . .	250 miles (400 km.)	200 miles (320 km.)

On the short waveband the ranges obtained depend upon the factors which govern the propagation of these waves, i.e. the actual wave-length used, the time of day and night, the season of the year, etc. Provided the correct conditions are selected, ranges varying from several hundred to several thousands of miles can be obtained.

The standard type A.D.37A/38A transmitting and receiving set comprises the following main items—

(1) Transmitter, complete with four valves.
(2) Receiver, complete with four valves.
(3) Microphone and telephone head-set, mounted in adjustable flying helmet.
(4) Manipulating key.
(5) Wind-driven generator, fitted with constant speed windmill.
(6) Accumulator battery, 6-volt 22·5 ampere-hour capacity.
(7) Trailing aerial supplies (aerial winch with aerial wire and bead-type weight and fairlead).
(8) Fixed aerial supplies (insulators, aerial wire, aerial-change-over switch, etc.)
(9) Set of suspension brackets and sundry cables, etc., for wiring up.

5. Marconi Type A.D. 57/5872, Telephone Telegraph Transmitter and Receiver, with Visual and Aural Direction Finding and Homing Equipment

The Marconi medium and short wave transmitting and receiving equipment, type A.D. 57/5872 is particularly suitable for large commercial, naval, and military aircraft operating over long routes and in which the conditions of service require a wide choice of operating wave-lengths.

THE TRANSMITTER TYPE A.D. 57 consists of two separate transmitter panels mounted in one box (Fig. 102). One panel carries the medium wave equipment, and the other the short wave equipment. Each panel is complete with its own valves, master oscillators, power amplifiers, feed meters, switching arrangements, etc.

The box is constructed of duralumin sheet, riveted, and sprayed in non-inflammable Marconi aircraft grey paint. The chassis is of aluminium, riveted and sprayed in non-inflammable Marconi light grey paint. The components are of high grade insulating material, aluminium and copper, with maconite wiring, and full tropical finish. All screws and nuts are fitted with locking devices.

The instrument boxes are of rigid construction and are fitted with a special quick release anti-vibration suspension, to protect them from shock.

The medium waveband for transmitting is 600–1100 metres (500–272.7 kcs.) covered in one range.

Transmission can be effected on continuous waves, interrupted continuous waves or telephony.

The power in the aerial circuit is approximately 66 watts on C.W., I.C.W., and telephony.

Assuming communication with a modern airport receiver, reasonable freedom from interference and transmission over agricultural country, the

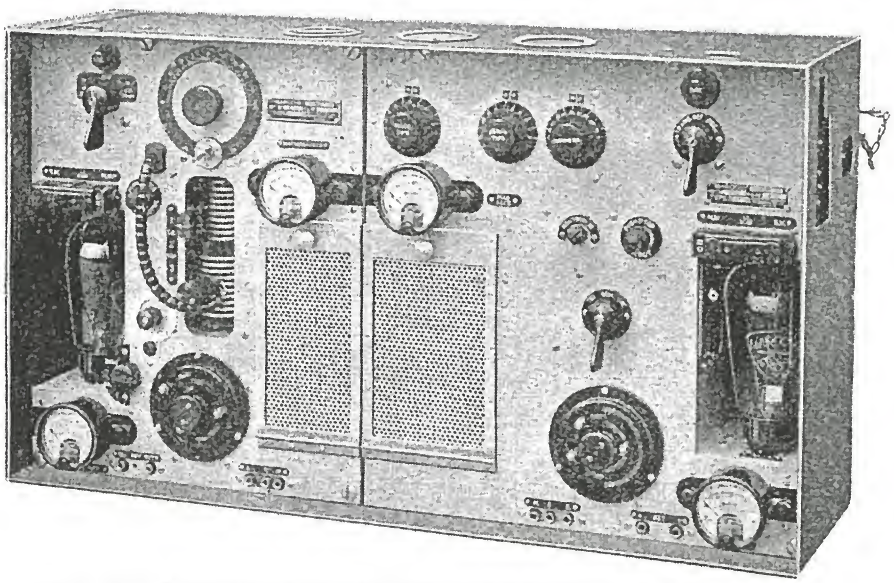


FIG. 102. MARCONI AIRCRAFT MEDIUM/SHORT-WAVE TRANSMITTER, TYPE A.D.57/A

following approximate ranges will be obtained when using a trailing aerial—

Air to ground C.W.	400 miles (640 km.)
Air to ground I.C.W.	300 miles (480 km.)
Air to ground Telephony . . .	200 miles (320 km.

The medium-wave transmitter circuits consist of a valve master oscillator circuit driving an air-cooled anode power amplifying valve.

The master oscillator tuning condenser is calibrated directly in metres, and by means of a click stop arrangement 4–5 pre-determined spot wave-lengths can be rapidly and accurately selected.

Special easily detachable feed meters are provided in the master oscillator and power amplifier anode circuits.

Telephony modulation is effected by the use of a modulator valve operating as a variable grid leak in the grid of the power amplifier valve. The depth of modulation is approximately 60 per cent.

Telegraphy is effected by keying across a resistance in the high-tension negative supply. With the manipulating key open, a heavy negative bias is put upon the grids of the master oscillator and power amplifier valve and clear crisp cut-off results.

For interrupted continuous waves, an interrupter disc mounted on the

high-tension generator and connected in series with the manipulating key produces an audible note of approximately 1000 cycles per second.

The high-tension input to the power amplifier valve is approximately 132 watts.

The total high-tension input to the medium wave transmitter is 1,200 volts at 144 milliamperes.

The total low-tension input is approximately 42 watts at 12 volts 3·5 amperes.

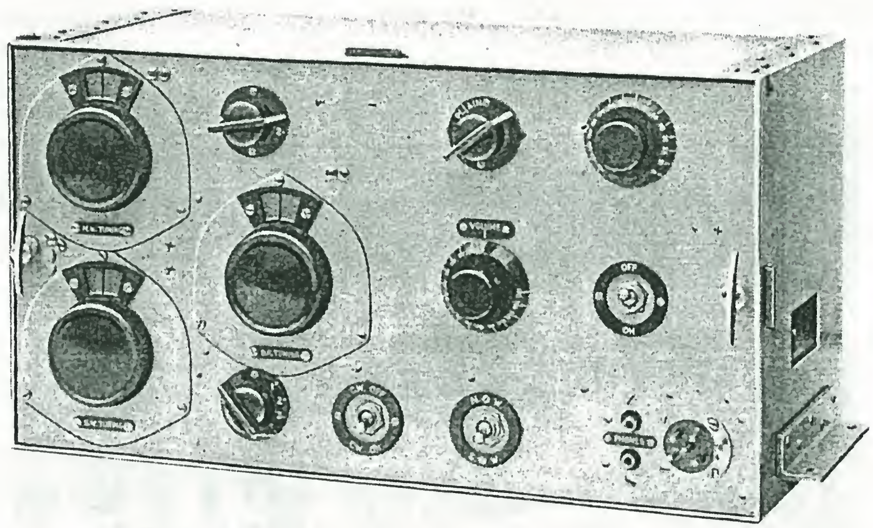


FIG. 103. MARCONI AIRCRAFT MEDIUM/SHORT WAVE AND D.F. RECEIVER TYPE A.D. 5872A

The medium-wave transmitter has the following controls—

(1) M.W. transmit/off stand-bi switch (or receive).
(2) C.W./I.C.W./Tel. switch.
(3) Master oscillator tuning condenser.
(4) Anode tap selector.
(5) Aerial tap selector.
(6) Aerial variometer.
(7) Neutrodyne switch and neutrodyne condenser.

The valves are arranged to be heated from the 12-volt supply, the correct operating voltage being maintained on the valves by series and parallel resistances.

(1) The master oscillator valve is a triode, Marconi type DET. 5. An oxide coated filament is used operating at 4 volts 2 amperes. The maximum anode voltage is 400 volts.

(2) The power amplifier valve is an air-cooled-anode triode, Marconi type ACT. 6. An oxide coated filament is used operating at 10 volts, 1·5 amperes. The maximum anode voltage is 1,200 volts.

(3) The modulator valve is a triode, Marconi type MHL. 4. An indirectly heated filament is used operating at 4 volts 2 amperes.

The waveband of the short wave transmitter is 16·9–75 metres (17,750–4,000 kcs.) covered in three ranges of approximately 16·9–27·3 metres (17,750–10,990 kcs.), 32–56 metres (9,380–5,337 kcs.), and 50–75 metres (6,000–4,000 kcs.). The transmitter is designed for continuous wave transmission only, and the power in the aerial circuit is approximately 60 watts.

On the short waveband the ranges obtainable depend upon the factors governing the propagation of these waves, i.e. wave-length, diurnal and seasonal variations, etc.

Provided the correct wave-lengths are chosen, ranges varying from several hundreds to several thousands of miles can be obtained.

The short-wave transmitter circuits consist of a valve master oscillator circuit driving an air-cooled anode triode power amplifier valve.

The master oscillator tuning condenser is calibrated directly in metres. A click-stop arrangement on the master oscillator control permits of the rapid and accurate setting of 4–5 predetermined spot wave-lengths.

Special easily detachable feed meters are provided in the master oscillator and power amplifier anode circuits.

Telegraphy is carried out by the same method as that used on the medium-wave panel.

The high-tension input to the power amplifier valve is approximately 120 watts.

The total high-tension input is 1,200 volts at 130 to 145 milliamperes.

The total low-tension input is approximately 42 watts at 12 volts 3·5 amperes.

The short-wave transmitter has the following controls—

(1) Main master switch, M.W. Transmit and S.W./M.W./Receive/Off short-wave transmit.

(2) Master oscillator tuning condenser.

(3) Master oscillator wave-range selector switch.

(4) Aerial circuit tuning condenser.

(5) Aerial circuit wave-range selector switch.

(6) Aerial tap.

(7) Neutrodyne switch and neutrodyne condenser.

The master oscillator valve is a Marconi triode, type DET. 5, and the power amplifier valve is a Marconi triode, with air-cooled anode, type ACT. 6.

The Receiver Type A.D. 5872

The direction finding receiver type A.D. 5872 employs a high efficiency superheterodyne circuit using multi-electrode valves. (Fig. 103.)

Reception can be effected on C.W., I.C.W., and telephony.

On the medium waveband, the circuit arrangement allows of the receiver being used for direction finding and "homing" with the addition of a rotatable screened frame aerial and a D.F. reversing switch.

By the addition of a visual indicator and a rotary reversing switch, visual course indication can be provided.

The receiver is continuously adjustable between the following limits—

Medium wave-range: 600–2,000 metres (500–150 kcs.) in two ranges of 600–1,050 metres (500–285·7 kcs.) and 1,050–2,000 metres (285·7–150 kcs.).

Short wave-range: 15–75 metres (20,000–4,000 kcs.) in four ranges 15–22 metres (20,000–13,740 kcs.), 21–33 metres (14,290–9,090 kcs.), 33–51 metres (9,090–5,828 kcs.), and 50–75 metres (6,000–4,000 kcs.).

The receiver is a superheterodyne of modern design, employing six indirectly heated valves with filaments operating at 12 volts. The valves perform the following functions.

(1) Two triode-hexode frequency changers, or "mixers" are used; one for the medium waveband, and the other for the short waveband, with the object of avoiding switching at high frequencies. This valve operates as

an H.F. amplifier, first detector, oscillator, and mixer valve. These valves are Marconi type X. 31.

(2) A variable amplification factor H.F. pentode acts as an intermediate frequency amplifier, working at an intermediate frequency of 465 kcs. The valve is a Marconi type W. 30.

(3) A double diode H.F. pentode acts as a further intermediate frequency amplifier, as second detector and as first stage L.F. amplifier. The valve is a Marconi type WD. 30.

(4) A triode valve Marconi type H. 30 acts as a second audio frequency magnifier.

(5) A separate triode valve Marconi type H. 30 acts as a heterodyne on the intermediate frequency for the reception of C.W. signals.

There are therefore four valves in circuit when receiving telephony or I.C.W. telegraphy, and five valves in circuit when receiving C.W., on either the short or medium wave-range.

Two independent tuning dials are provided, one for each waveband. They are directly calibrated in metres and are illuminated when in use.

The receiver has the following controls—

(1) Medium wave ganged tuning condensers.
(2) Short wave ganged tuning condenser.
(3) Medium wave/short wave selector switch.
(4) Medium wave range switch.
(5) Short wave range switch.
(6) Manual volume control.
(7) C.W. reception switch.
(8) Main receiver on/off switch.

Additional direction finding controls incorporated in the receiver are—

(1) D.F. frame tuning condenser.
(2) D.F./Plain aerial selector switch.
(3) Zero clearing control.

The total high-tension input to the receiver is approximately 30 milliamperes at 180–200 volts.

The total low-tension input to the receiver is approximately 2·4 amperes at 12 volts, each valve filament taking 0·3 ampere.

On medium wave-lengths the average selectivity is such that a given signal is reduced by 30 db. if the receiver is adjusted to 10 kcs. off tune.

From 600–1,000 metres a 12-microvolt signal input gives an output of 10 milliwatts. From 1,000–2,000 metres a 16-millivolt signal input gives an output of 10 milliwatts. The maximum undistorted power output, approximately 150 milliwatts.

If specially required, "listening through" can be provided at a small extra cost. This enables the operator to listen for interruptions from the ground station in the intervals between keying, during telegraphy operation. A special small dipole aerial is provided, and is connected to the receiver during telegraph transmission, the receiver being kept in operation all the time. When the key is pressed, this dipole aerial is shorted to earth, so that the receiver does not get overloaded, but receives only enough to act as "sidetone." When the key is open, the dipole is unshorted and the receiver can pick up any interruption message sent out by the ground station. This arrangement saves much time in service, especially when approaching an aerodrome as the ground control station can break in and stop the aircraft transmitting at any moment, instead of having to wait until the aircraft operator completes his message and changes over to receive.

If "listening-through" is provided, the sidetone circuits in the S.W. and M.W. transmitter panels are not used. If "listening-through" is not provided, the usual sidetone circuits operate, and the operator hears his own C.W., I.C.W., or telephony transmission. C.W. sidetone is made

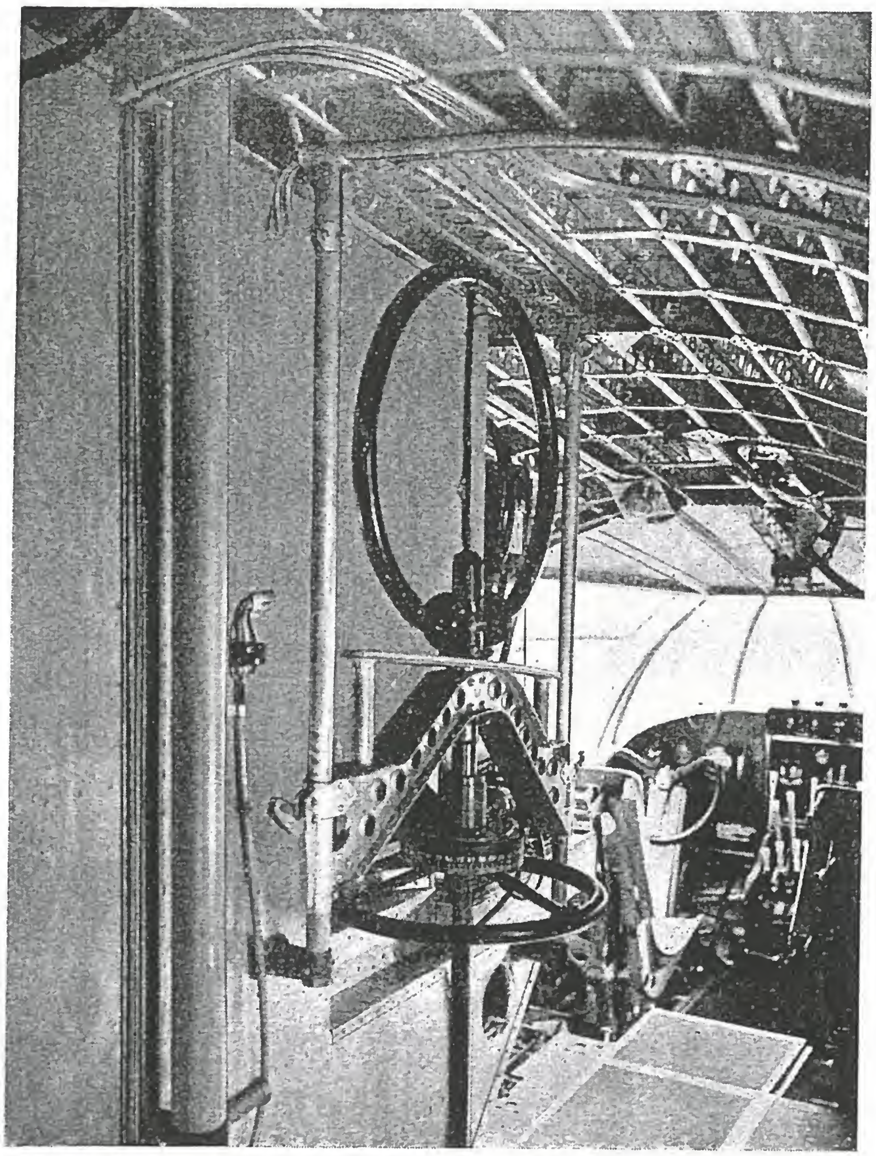


FIG. 104. MARCONI 19″ D.F. ROTATABLE LOOP AERIAL, WITH RETRACTABLE MOUNTING

View showing aerial fitted to Imperial Airways Flying Boat "Canopus."

audible by means of a special interrupter circuit, which makes the C.W. sidetone sound like I.C.W., although only pure C.W. is actually transmitted.

For *direction finding and "homing"* with the A.D. 5872 receiver, the following items of equipment are required—

Rotatable Frame Aerial (Fig. 104)

This is a rigid circular screened frame 19 in. (48 cms.) outside diameter, mounted outside the aircraft fuselage, and operated from inside by means of a hand wheel. A circular engraved scale and pointer indicate the angle at which the frame aerial is set in relation to the nose of the aircraft. Bearings can therefore be taken on stations in the usual manner, or the frame can be set at right angles to the line of flight for "homing." By the addition of a visual indicator the facilities of a radio compass are provided.

An automatic clutch in the frame mechanism locks the frame in any desired position as soon as rotation by hand is stopped.

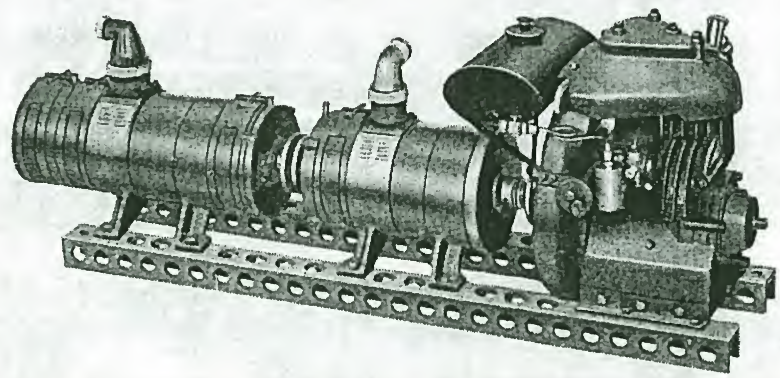


FIG. 105. POWER PLANT FOR MARCONI AIRCRAFT EQUIPMENT TYPE A.D. 57A/5872A MOTOR GENERATOR SET AND EMERGENCY PETROL ENGINE

The frame can be made retractable if desired.

When using D.F. the output from the frame together with that from the open aerial is coupled via a suitable transformer in the A.D. 5872 receiver.

The *hand reversing switch* provides aural "homing." It reverses the phase of the open aerial coupling to the frame aerial, thus producing louder or weaker signals if the aircraft is off course. It is thus possible to steer the aircraft on to its true course, when the signals will become equal, regardless of the phase of the open aerial coupling. An adjustable open aerial phasing resistance is also mounted in the switchbox. This is used to equalize the input from the open aerial with that from the frame aerial.

For visual operation the hand switch is set in its middle position.

The visual indicator consists of a centre-reading dashboard instrument, together with a rotating commutator reversing switch, which is driven by a separate 12-volt motor (or by the anode converter). This switch reverses the trailing aerial coupling and also the input to the indicator so that a visual indication of the side off course is given on the indicator. It is thus possible to use the equipment either for visual or aural methods of "homing" at will.

ACCURACY FOR "HOMING." When using "homing" with the open aerial in conjunction with the frame, off-course indications are easily detectable aurally with an accuracy of $\pm 2°$ and with an accuracy of $\pm 3°$ for visual indication.

When using the frame aerial alone, on minimum signal, accuracies within $\pm 2°$ are audible, or visible, at ranges up to 150–200 miles (240–320 km.) depending upon the power of the transmitter, and assuming good reception conditions.

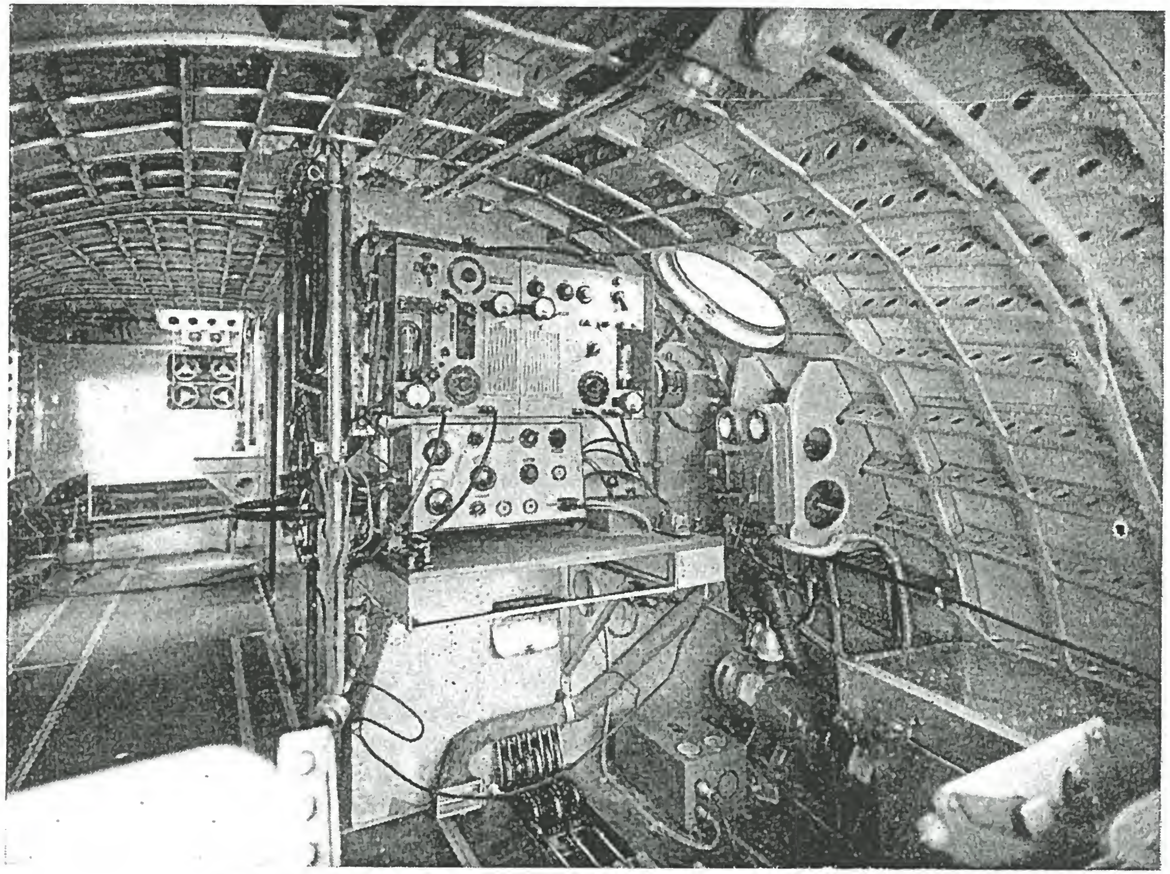


FIG. 106. MARCONI AIRCRAFT EQUIPMENT TYPE A.D. 57A/5872
View showing equipment installed in Imperial Airways Flying Boat "Canopus."

For short and medium wave transmission and non-directional reception, trailing aerial and fixed aerial are provided.

A special dipole aerial is supplied in addition if listening through is required.

For directional reception a rotatable screened frame aerial is used, working in conjunction with either the trailing or fixed aerial for "homing" or direction finding.

The transmitter power equipment when used on large flying boats usually consists of a motor generator set in which the motor runs off the 24-volt aircraft low-tension supply, and the double output generator supplies 12-volt low-tension and 1,200-volt high-tension to the transmitter.

The motor takes an input of 698 watts at 24 volts 27 amperes.

The double output generator delivers a high-tension supply of 1,200 volts at 200 milliamperes and a low-tension supply of 12·5 volts 6 amperes.

For emergency working or for charging the aircraft 24-volt batteries when the main engine driven generators are not in use, a 1 h.p. Marconi Stanley two-stroke petrol engine is coupled by means of a quick release coupling to the motor generator set contained in the same bedplate. The 24 volt motor is then used as a generator and delivers 390 watts at 26 volts 15 amperes (Fig. 105).

The Marconi Stanley engine can be started up by motoring the 24-volt generator from the aircraft batteries.

The receiver high-tension is derived from an anode converter running off the aircraft 12- or 24-volt low-tension supply and delivering a high-tension supply of 180 volts 30 milliamperes.

If the motor-generator-petrol engine set is not required, the usual wind-driven generator equipment, either for wireless supplies only, or for charging and lighting services in conjunction with a special charging switchboard, can be supplied. With these wind-driven generators, the receiver high-tension supply is derived from the main generator, no separate anode converter being required. Alternatively, the equipment can be run (at low power) from a rotary transformer fed from the aircraft accumulators. This rotary transformer has an output of 1,000 volts 150 milliamperes and provides the transmitter with approximately 90 watts on the anodes, or 45 watts in the aerial circuit.

Below are given approximate weights and dimensions of the equipment (Fig. 106)—

				Weight lb.	oz.	kg.
Transmitter, Type A.D.57	Width .	25¼ in.	(64·7 cms.)	43	0	(19·5)
	Depth .	8½ in.	(21·5 cms.)			
	Height .	14½ in.	(36·8 cms.)			
Receiver, Type A.D.5872 .	Width .	16¼ in.	(41·2 cms.)	16	2	(7·3)
	Depth .	8¾ in.	(22·2 cms.)			
	Height .	9 in.	(22·8 cms.)			
Visual indicator rotary switch	Width .	12 in.	(30·5 cms.)	7	3	(3·25)
	Depth .	4 in.	(10·2 cms.)			
	Height .	6 in.	(15·24 cms.)			
Aerial change-over switch.	Width .	5¾ in.	(14·6 cms.)	1	4	(0·56)
	Depth .	5 in.	(12·7 cms.)			
	Height .	3 in.	(7·6 cms.)			
Visual indicator meter .	Overall diameter	3½ in.	(8·85 cms.)		8	(0·22)
			Carried forward	68	1	(30·83)

		lb.	oz.	kg.
	Brought forward	68	1	(30·83)
Screened rotatable frame aerial	Max. dia. 19 in. (48·3 cms.)	13	8	(6·1)
Trailing aerial supplies		7	11	(3·5)
Fixed aerial supplies		4	0	(1·85)
Dipole aerial supplies		4	0	(1·85)
Engine generator set with emergency petrol engine		111	8	(50·5)
Switchboard		11	3	(5·1)
Headset, complete		1	6	(0·62)
Operating key			8	(0·22)
Cables (average)		10	0	(4·5)
	Total approximate weight of equipment	244 lb.		(110) kg.

The table below gives particulars of Marconi-Newton type generators and the type of set with which they are designed to work. The windmills designed to drive these generators are of the automatically variable pitch

Type of Generator	High Tension		Low Tension		R.P.M.	Weight		Type of Transmitter
	Volts	Amps.	Volts	Amps.		lb.	oz.	
A.D./Q1	1,200	0·2	16	16	3,500	35	11	For A.D. 41/42 and A.D. 37/38
A.D./Q2	1,200	0·2	16	16	3,500	35	11	
A.D./R1	1,200	0·2	7	10	3,500	24	6	
A.D./R2	1,200	0·2	7·5	10	3,500	25	0	
*A.D./U1	1,000	0·15	16·5	14	3,500	26	12	
†A.D./U2	1,000	0·15	16·5	14	3,500	29	0	
*A.D./U5	1,000	0·15	16·5	14	3,500	27	0	
†A.D./U6	1,000	0·15	16·5	14	3,500	29	4	
*A.D./U9	1,000	0·15	16·5	14	3,500	27	0	
A.D./H14	1,000	0·15	—	—	3,500	12	0	
*A.D./U10	800	0·13	16·5	14	3,500	26	12	For A.D. 49/50
A.D./H12	800	0·13	12·5	3·25	3,500	14	0	
*A.D./H15	800	0·13	12·5	3·25	3,500	14	12	

* For tunnel mounting in the leading edge of the wing.
† For cradle mounting.

type, which ensure constant voltage almost irrespective of load and air-speed. There is a range of these windmills, and reference should be made to the maker as to the most suitable one to use with a given generator and

aircraft, but the following table gives some particulars of the different types—

Type	Drg. No.	Range of Total Airspeeds over Windmills*	Corresponding Range of r.p.m.	Generator for which approved
Marconi Newton,				
Type 110 . .	18267	70–170 m.p.h.	Approx. 3,500 r.p.m.	Any approved type of electrical generator
,, 112 and 112 S.	18645	70–300 ,,		
,, 140 . .	18267	70–170 ,,		
,, 142 and 142 S.	18645	70–300 ,,		
,, 160 . .	18267	70–170 ,,		
,, 180 . .	18267	70–170 ,,		
,, 182 and 182 S.	18645	70–300 ,,		

* Including slipstream if any.

When Marconi-Newton Constant Speed Windmills, types 110, 140, 160 and 180, are used, it is essential that the following instructions be observed to ensure the correct functioning of their regulating mechanism.

(1) The windmills are to be tested before each flight for freedom of the blades. For this purpose the blades are to be turned against the force of the internal springs in the direction to coarsen their pitch, care being taken that the blades are gripped as near as possible to the centre to avoid damaging or distorting the blades.

(2) The windmills are to be lubricated after approximately every 20-hours' flying by means of a few drops only of very light machine oil introduced into the hole provided.

THE WESTINGHOUSE G.D. TRANSMITTER, with a power output of 15 watts, is designed primarily for the private owner. The unit operates from the standard 12-volt aircraft battery and incorporates a self-contained dynamotor. This feature reduces the amount of fitting necessary to the single unit and the remote control since only one battery cable and the remote control cable need be installed and the transmitter takes up very little space. It is recommended that a quarter wave trailing wire aerial be used, but the transmitter will operate satisfactorily with any type of fixed aerial. It is designed to operate at either 3,105 or 3,120 kilocycles, but can be supplied for operation on any two frequencies relatively close together between 2,000 and 6,600 kilocycles. Transmitting frequency is maintained by low temperature coefficient plug-in type quartz crystals. The maximum output is 15 watts with 100 per cent modulation. The remote control incorporates one single toggle switch to control the filament current, another to select the desired transmitting frequency, and a microphone jack. The controls are supplied either in a standard aircraft instrument case or for separate mounting with individual nameplates. An aerial meter with a luminous dial fitted in a standard case as is used for aircraft instruments is also supplied. The dynamotor and its filter are mounted on the transmitter chassis and enclosed by the cover of the transmitter unit. Adequate overload protection is provided by fuses located both in the 12-volt supply line and in the high voltage anode circuit. A spare high voltage fuse is supplied with the unit and clipped on to the cover. The transmitter itself incorporates an amplifier stage, with two screen grid valves.

DIMENSIONS

Transmitter case: $12\frac{1}{2}$ in. × $8\frac{1}{2}$ in. × $7\frac{1}{2}$ in. (32·5 × 21·5 × 19·5 cm.).

Overall dimensions including Lord shock-absorber mountings and cable plugs: $15\frac{3}{8}$ in. × $8\frac{1}{2}$ in. × $8\frac{5}{8}$ in. (39 × 21·5 × 22 cm.).

Remote control cable length: 20 ft. (6·16 metres).

Battery control cable length: 4 ft. (1·22 metres).

Remote control metre case: 2 in. diameter (7 cm.).

Weight of complete transmitter: 25 lb. 14 oz. (11·8 kg.).

GENERAL MAINTENANCE OF W/T EQUIPMENT

All wireless equipment requires particular care, both in use and in store. If proper care is not exercised failure in communication is likely to result, and the faults which develop will be found difficult to locate.

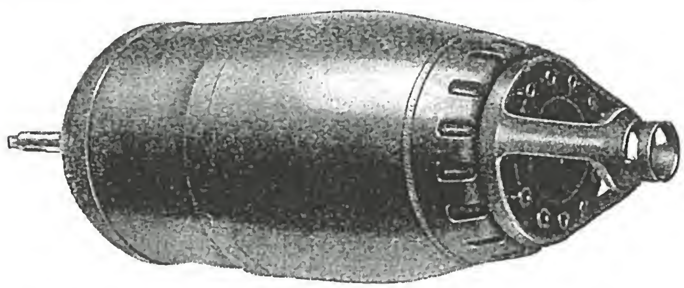


FIG. 107. M.L. AIR-DRIVEN GENERATOR: TYPE "K"
The M.L. Air-driven Generator is the latest machine to be added to the range of M.L. machines for aircraft.
(By courtesy of Rotax Ltd.)

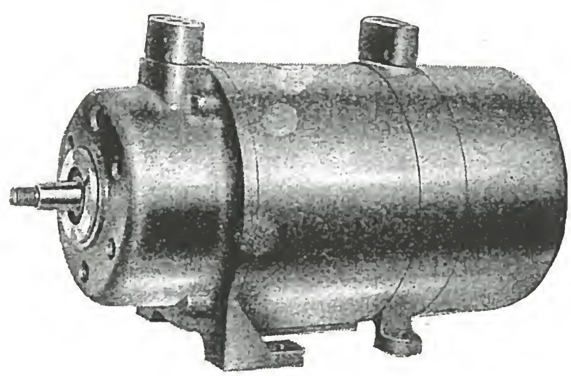


FIG. 108. M.L. ROTARY TRANSFORMER: TYPE "G"
The M.L. Rotary Transformer type "G" has been specially designed for radio transmission work on aircraft. Its chief features are extremely light weight, compact design.
(By courtesy of Rotax Ltd.)

Sand, dust, and other grit particularly must be guarded against. Instruments in use must be cleaned and dusted daily, or more often if required. Where dust storms are prevalent, dustproof covers should be made for instruments, and the latter should be removed from aircraft when not in use. All contacts must be kept clean. Files, or anything rougher than the finest grade emery cloth, should never be used on contacts, and fine contacts should be cleaned with tissue paper or a dry cloth.

Oil or grease on contacts must be guarded against, key contacts requiring particular attention in this respect.

Instruments should never be left in full sunshine, particularly in the East. This applies especially to instruments constructed of ebonite, which will soften and warp in the sun.

Dry cells (primary batteries) should not be stored in a hot place, as the heat will cause evaporation of the moisture in the cell. They should be stored vertically to allow any gas generated to escape uniformly. The terminals must be kept clean and free from sulphate, and every care must be taken to prevent short-circuiting. No short lengths of lead should be left lying about.

Dry (inert) cells should never be moistened until actually required.

In hot climates the deterioration of dry cells is very great; arrangements should be made for periodical turnover.

All equipment must be kept as dry as possible, and sea water particularly should not be allowed to reach any instrument. Damp enormously reduces the insulating properties of ebonite, woodwork, and insulation or wiring. Its effects are deceptive, and it is in the internal fittings, windings, and wirings that the danger of dampness particularly lies.

Insulators of an aerial system and of instruments must be carefully examined from time to time.

Ordinary clear dope is a plain solution of celluloid, and is a reasonably good insulator. Aluminium dope, however, may be quite a good conductor, especially where high voltages or radio frequency oscillations are concerned. It should not, therefore, be applied to any surface in contact with an aerial insulator or similar fitting within two or three inches of such fittings.

Head telephones should be examined daily to ensure that the telephone leads are not wearing, and that the small nuts are tight. Faults in head telephones are a very frequent source of failure.

Valves should not be handled more than necessary, and when not in use should always be kept in the boxes provided. The habit of shaking or tapping a valve is to be discouraged. Valves must not be forced into sockets; if properly handled, they will go in quite easily.

High-tension generators must be kept dry and free from dust. The clearance between the casing and the armature is small, and care must be taken to prevent the outer case (streamline cover) becoming dented or bent. Sparking is generally an indication of dirt and damp, and it is particularly likely to occur if a generator has not been used for some time.

Rotary Machinery—General. (*a*) Absolute cleanliness of all parts must be observed, and all machinery must be examined in detail periodically. Any heating above the normal must be carefully noted, as this is a certain indication of fault. (*b*) Commutators require particular attention. They must be kept absolutely clean, and it is essential that they should be "true" and that there should be a minimum of sparking at the brushes. A commutator should generally be cleaned when the machine is moving (to prevent "flats") with a rag, not cotton waste, damped with methylated spirit. Where possible, the brushes should be shifted occasionally along the rocker. Experience will teach how to avoid ordinary sparking, which is generally due to a loose or worn-out brush, or to a dirty commutator. Abnormal sparking often indicates a serious overload, or even a broken coil. Careful attention must be given to the lubrication of all bearings, and for this purpose anti-freezing grease is usually specified by the makers.

As a means of protection to aircraft whilst replenishing the fuel tanks, the structure of the aircraft should always be "earthed" whilst stationary

on the ground to prevent the building up of large static charges of electricity. This is usually accomplished through the tail skid or by means of a trailing conductor.

APPROVED RADIO APPARATUS

The undermentioned types of radio apparatus are at present approved officially for use on civil aircraft—

Type	*Range*
R.X.25 Receiver	600–5,000 metres (provisional)

TELEGRAPH-TELEPHONE SETS

Set	Type	Wavelengths in Metres
Marconi's Wireless Telegraph Co. Ltd.		
A.D.6	Transmitter	400–1,200
,,	Receiver	300–1,500
A.D.6A	Transmitter	400–1,200
,,	Receiver	850–950
A.D.6C	Transmitter	500–1,500
,,	Receiver	500–3,500
A.D.6H	Transmitter	300–1,500
,,	Receiver	200–1,800
A.D.6M	Transmitter	550–1,550
,,	Receiver	550–1,550
A.D.6N	Transmitter	550–1,150
,,	Receiver	500–1,300
A.D.8	Transmitter	600–1,500
,,	Receiver	600–4,000
A.D.18A	Transmitter	300–1,600
,,	Receiver	300–1,800
A.D.19	Transmitter	40–60
A.D.20	Receiver	15–150 (in four ranges)
A.D.20A	Receiver	80–180
A.D.22B	Transmitter	600 and 850–900
,,	Receiver	600–900
A.D.22C	Transmitter	600 and 850–900
,,	Receiver	600–900
A.D.22D	Transmitter	600 and 800–950
,,	Receiver	600–950
A.D.24A	Transmitter	30–60
A.D.37A/38A	Transmitter	40–80 and 500–1,000
,,	Receiver	40–1,000
A.D.37C/38B	Transmitter	40–80 and 500–1,600
,,	Receiver	40–80 and 500–1,600
A.D.37D/38C	Transmitter	35–70 and 500–1,000
,,	Receiver	35–70 and 500–1,000
A.D.37E and Rotary transformer	Transmitter	40–80 and 500–1,000
,, ,, ,,	Receiver	500–1,000
A.D.37F/38D	Transmitter	150–200 and 500–1,000
,,	Receiver	150–200 and 500–1,000
A.D.37H/38F	Transmitter	40–80 and 500–1,000
,,	Receiver	40–80 and 500–1,000
A.D.41A/42A	Transmitter	500–1,000
,,	Receiver	500–1,000
A.D.41B/42B	Transmitter	500–1,000 (in two ranges)

TELEGRAPH-TELEPHONE SETS—*Continued*

Set	Type	Wavelengths in Metres
A.D.41C/42C	Transmitter	500–1,000 (in two ranges)
,,	Receiver	500–1,000
A.D.41C/5062B	Transmitter	500–1,000 (in two ranges)
,,	Receiver	600–1,550 (in two ranges)
A.D.43A/44A	Transmitter	50–100
,,	Receiver	50–100
A.D.43C/44B	Transmitter	50–130
,,	Receiver	50–130
A.D.49A/50A	Transmitter	600–1,000
,,	Receiver	600–1,200
A.D.49A/5062A	Transmitter	600–1,000
,,	Receiver	600–1,200
A.D.49A/50B	Transmitter	600–1,000
,,	Receiver	600–1,550 (in two ranges)
A.D.49A/5062B	Transmitter	600–1,000
,,	Receiver	600–1,550 (in two ranges)
A.D.51A	Transmitter	147·8–144·9
,,	Receiver	147·8–144·9
A.D.57A/5872A	Transmitter	16·9–75 (in three ranges) 600–1,100
,,	Receiver	16–75 (in four ranges) and 600–2,000 (in two ranges)
A.D.73A/37K/5872B	Transmitter	16·9–75 (in three ranges) 90–190 and 500–1,000
,,	Receiver	15–100 (in five ranges), 183, 300–450 and 600–2,000 (in two ranges)
Plessey Co. Ltd.		
A.C.44	Transmitter	600–930
,,	Receiver	600–930
A.C.57	Transmitter	40–80
,,	Receiver	550–1,350
Standard Telephone and Cables Ltd.		
A.T.R.4	Transmitter	500–1,100
,,	Receiver	500–1,100
A.T.R.6	Transmitter	30–80
,,	Receiver	500–1,000
A.T.R.7	Transmitter	500–1,100
,,	Receiver	500–1,100
A.T.R.8	Transmitter	30–120
,,	Receiver	30–120
A.T.R.4002 S/N.1	Transmitter	30–60 and 600–1,200
,,	Receiver	30–1,200

CHAPTER VII

DIRECTIONAL WIRELESS

DIRECTIONAL wireless, as applied to position finding and the navigation of aircraft, has now reached such a stage of reliability that it has made the navigation of aircraft, particularly in fog and over clouds, very much more certain than have any other methods that have so far been used. Various systems have been developed, but so far as the navigation of civil aircraft is concerned, the choice of at least four methods is now available.

1*st Method.* The object is attained by the transmission of a wireless signal from the aircraft, and the reception of this signal by a particular ground station fitted with special apparatus which enables the operator to ascertain the direction, or bearing from true north, of the aircraft when the signal was received. The bearing is then transmitted by wireless from the ground station to the aircraft.

The apparatus required in the aircraft consists of the ordinary wireless transmitter and receiver, capable of sending and receiving signals over the distance at which the aircraft is operating from the special ground station.

By arranging a second direction-finding receiving station on the ground at the other end of a suitable base line, both stations can take a bearing simultaneously on the aircraft. The second station notifies to the first, or control station, its result, the control station plots this bearing and its own on a map, and obtains an intersection which gives the actual position of the aircraft. The control station can then signal to the aircraft, e.g. 5 miles S.S.E. of Calais. With skilled operators at the ground stations, the position thus found should be accurate to within 3 miles at a range of 150 miles. The aircraft personnel require some training to be able to make the best use of their transmitters and receivers, as speed is essential to accuracy.

The advantages of this system are the simplicity of operation in the aircraft, no apparatus other than that ordinarily required for communication with the ground being necessary, and the use that can be made on the ground of complicated instruments to give great accuracy and reliability.

2*nd and* 3*rd Methods.* The Marconi type A.D. 52 direction-finding attachment (Fig. 104) is designed for use in conjunction with Marconi aircraft receivers. Although designed primarily for use with the types A.D. 38 and A.D. 42 receivers, it is also suitable for use with the majority of Marconi medium wave aircraft receivers. The D.F. attachment eliminates the necessity of providing a complete direction-finding receiver in addition to the normal receiver, thus effecting a saving in cost, weight, and space.

The type A.D. 52 attachment is designed for operating on either of two systems of direction finding, namely—

(1) The Fixed Aerial "Homing" System, in which use is made of a single fixed loop aerial in conjunction with a trailing aerial and a loop reversing switch.

(2) The Rotatable Loop Aerial System, which enables bearings of a transmitter to be taken in the usual way, but also retains the special features of the "Homing" system.

The provision of direction-finding facilities in no way interferes with

the normal reception carried out on the trailing aerial, change from normal reception to direction finding being instantaneously effected by means of a small change-over switch mounted in the D.F. attachment.

The attachment is designed to cover a wave-range of 500 to 1,550 metres (600–193·5 kcs.) in two ranges of approximately 500 to 1,100 and 900 to 1,550 metres.

It should be noted that this wave-range will be curtailed when the attachment is used with a receiver having a wave-range less than 500 to 1,550 metres.

Fig. 109

A = Loop tuning condenser. *C* = "D.F."-plain aerial change-over switch.
B = H.F. tuning condenser. *D* = Loop reversing switch.

The Homing System. This is essentially a simple method which enables a pilot to set the course of his aircraft directly towards a known wireless transmitter on the ground. It is particularly suitable for use on aircraft where no special wireless operator and/or navigator is carried, and where the aircraft flies mainly on routes possessing no direction-finding stations on the ground, but where ground communication or beacon transmitters are situated along the route, e.g. at the various aerodromes.

In this system use is made of a single loop aerial installed so that its plane lies at right angles to the fore and aft line of the aircraft, and a loop reversing switch in addition to the normal receiver and trailing aerial.

The loop reversing switch incorporates a three-position switch, and adjustable resistance.

In the *central* position of the switch the loop aerial alone is connected to the receiver; in the *left*-hand position both the loop aerial and the trailing aerial are connected to the receiver, while in the *right*-hand position both the loop aerial and the trailing aerial are connected to the receiver, but the connections of the loop aerial are reversed.

If the aircraft is flying head-on towards the transmitting station, no E.M.F. is induced in the loop aerial and only the signal due to the trailing aerial will be heard when both trailing aerial and loop aerial are connected. Further, under these conditions no difference will be observed whether the switch is moved to either the left or the right.

If, however, the aircraft is not flying head-on towards the transmitting station an E.M.F., depending on the angle of divergence, will be induced in the loop aerial. Now, on moving the switch from side to side the resul-

tant signal strength will be greater if the loop aerial is connected to the receiving apparatus in one direction and less if the loop aerial connections are reversed. From these indications it can be determined whether the transmitting station lies to port or starboard of the fore and aft axis of the aircraft. By suitably correcting the course until no difference in signal strength can be observed, whichever way the loop is connected, the aircraft will be automatically "headed" towards the transmitting station. The accuracy of the course can be checked by putting the switch in the central position (connecting only the loop aerial) when, if the course is correct, no signals at all will be heard.

The adjustable resistance enables the strength of the signal due to the trailing aerial to be made approximately equal to the strength of signal due to the loop aerial and provides a useful indication of the deviation off course. A characteristic of this system is that, in the case of a strong cross wind, the path followed by the aircraft will not be a straight line but will be a curved line, somewhat of parabolic shape depending on the strength of the cross wind. The nose of the aircraft will always point towards its objective, but as the aircraft is blown off its straight-line course its compass bearing will be progressively changing and the machine will eventually arrive more or less "nose into wind," at the desired aerodrome.

THE ROTATING LOOP SYSTEM. This system provides a full direction-finding service in cases where an operator and/or navigator is carried on large civil, military, or naval aircraft, and which fly over territory where no direction-finding stations are available, or over sea. The system enables the aircraft to be headed towards a transmitting station as previously described under "Homing" system, and, in addition, provides a convenient means whereby bearings may be taken on stations which lie off the normal course of the aircraft, and from which the position of the aircraft may be determined by plotting, in the usual way, the bearings of two or more such stations on a chart.

In this system use is made of a small screened loop aerial mounted externally on the aircraft and provided with a hand-wheel and mechanism for rotating the loop from inside the aircraft. The mechanism incorporates a clutch, so arranged that the loop is automatically locked in the desired position when the hand-wheel is released.

The method of taking bearings is similar to that already described under the "Homing" system, so that if "homing" only is required it is only necessary to set the loop at right angles to the fore and aft axis of the aircraft, to operate the loop reversing switch, and to correct the course accordingly. In the case of bearings taken on stations lying off the line of flight, however, the reversing switch is set in the central position and no signal is heard from the transmitting station. The reversing switch is operated and no difference in signal strength can then be observed whichever way the loop is connected, the signal heard being due to that received on the trailing aerial only. When this condition is obtained, the bearing of the desired station relative to the "head" of the aircraft may be read from a scale attached to the mechanism.

The equipment required in addition to the normal receiver for operating on the two methods of direction finding comprises the following—

(1) *Fixed Loop "Homing" System.*

(*a*) A two-stage tuned H.F. amplifier and a loop tuning circuit.

(*b*) A loop reversing switch unit.

(*c*) A fixed loop aerial.

(*d*) Interconnecting leads.

(2) *Rotatable Loop System.*

As for (1), but employing a rotatable screened loop in place of the fixed loop (Item (*c*) above).

The type of loop aerial used depends upon the size and type of aircraft. In the case of a biplane of *wooden* construction it is usually possible to mount the fixed loop aerial round the wings and struts or alternatively round the fuselage itself. In the case of an *all-metal* aircraft, however, the foregoing arrangements are not possible and in such circumstances a *small rotatable screened loop aerial* is mounted externally on the aircraft.

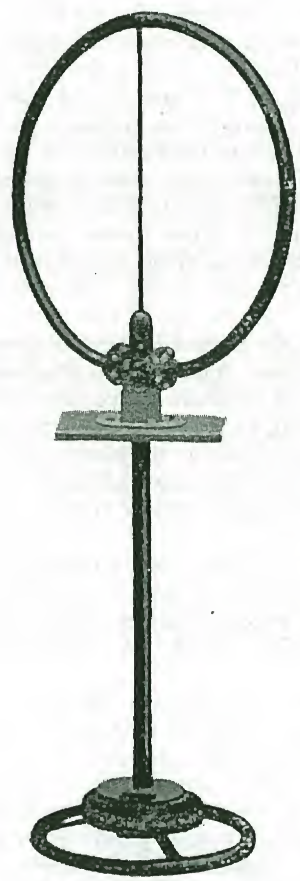


FIG. 110

ROTATABLE SCREENED LOOP AERIAL

The screened loop aerial can be of the retractable type if required, whereby the loop can be drawn into the body of the aircraft when D.F. observations are not required.

THE HIGH-FREQUENCY AMPLIFIER unit consists of a panel on which are mounted a circuit for tuning the loop aerial to the required wavelength: a two-stage screen-grid high-frequency amplifier and a "D.F.-Plain Aerial" change-over switch.

The tuning control of the loop tuning circuit is calibrated in metres at the time of installing, as the calibration depends upon the electrical characteristics of the loop aerial when fitted.

The tuning condensers of the two high-frequency amplifying stages are simultaneously adjusted by a single dial calibrated directly in metres.

The valves used in each of the high-frequency stages are type S 610 or S 410, according to the type of receiver with which the attachment is used.

The "D.F. Aerial" switch performs the following operations—

(1) When at "Plain aerial" it causes the loop aerial to be earthed, disconnects the two-stage amplifier and connects the trailing aerial direct to the receiver for ordinary reception.

(2) When at "D.F." it connects the loop aerial and the H.F. amplifier into circuit for direction-finding purposes.

The complete panel is contained in a light metal case and can be either bolted directly to the main wireless receiver or mounted separately according to requirements.

The type A.D. 52/42 forms a complete direction finding and receiving equipment which can be used with either the fixed or rotatable aerial system previously referred to in the description of the type A.D. 52 direction-finding attachment.

The equipment is particularly suitable for use in cases where transmission is not required, or where a separate transmitter is installed in the aircraft.

The direction-finding unit (type A.D. 52) and the receiver (type A.D.42) are mounted together to form a composite unit. The type A.D. 42 receiver incorporates a screen-grid high-frequency amplifying valve, a detector valve with reaction coupling and a pentode output valve.

The type A.D. 52/42 direction-finding receiver is designed to cover a wave-range of 500 to 1,000 metres (600–300 kcs.).

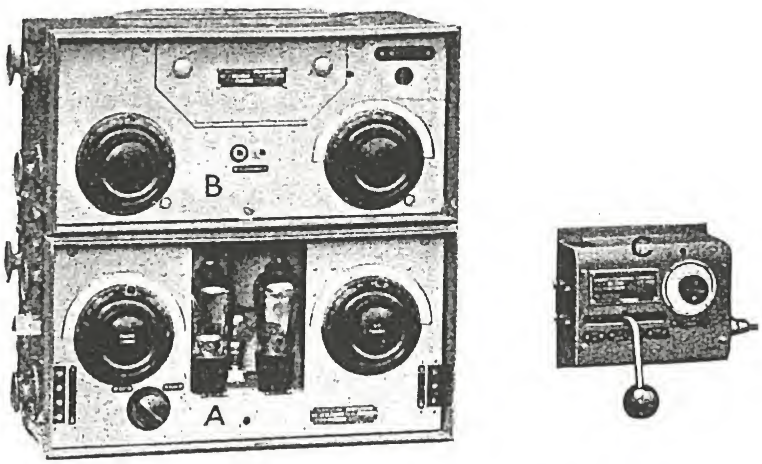


FIG. 111. MARCONI D.F. RECEIVER, TYPE A.D.52/42

Marconi Aircraft D.F. Receiver Type A.D. 5062B, with Visual Indicator Type 626

The type A.D. 5062B direction-finding receiver is designed for use either as a separate receiving station in aircraft, or in conjunction with the medium wave Marconi aircraft transmitters, e.g. types A.D. 41, A.D. 49, in which cases it replaces the receivers type A.D. 42 and type 50 receivers normally used with those equipments.

The direction-finding receiver consists of the A.D. 50B receiver panel together with an A.D. 62B D.F. panel, mounted in one box as a complete unit, and used in conjunction with either a fixed or rotatable screened frame aerial and, if desired, the visual indicator type 626. The D.F. receiver can, therefore, be used either for aural working or for visual indicator working, in which latter case it becomes what is usually known as "a radio compass."

The provision of direction-finding facilities in no way interferes with the normal reception carried out on the trailing or fixed aerial, a change-over switch being provided for instantaneous switching to ordinary reception or to direction finding as required.

The wave-range covered by the receiver is 600–1,550 metres (500–193·5 kcs.) in two ranges of approximately 600–1,200 metres and 1,100–1,550 metres.

Two systems of direction-finding are available, namely—

(*a*) The fixed aerial "homing" system in which use is made of a single fixed screened frame aerial in conjunction with an open aerial (fixed or trailing as convenient), the open aerial coupling to the fixed frame aerial being reversed by a hand-operated switch mounted in the A.D. 62 panel.

(*b*) The rotatable frame aerial system, which enables bearings of a transmitter to be taken in the usual way, but which also retains the special features of the "homing" system.

Under normal conditions "off-course" indications can easily be detected at 3 degrees either side of true course. When using the frame aerial alone, on minimum signal, accuracies within $\pm$ 2 degrees are obtainable up to

150–200 miles (240–320 km.), depending upon the power of the transmitter, and the absence of radio or other interference.

The approximate sensitivity of the whole receiver is such that an input of approximately 6 microvolts will give an output of 10 milliwatts. The receiver will give an output up to approximately 150 milliwatts without distortion.

The selectivity varies somewhat with the reaction adjustment, but when normally adjusted for telephony reception is such that the output is reduced by 35 db. when the receiver is 10 kcs. off tune.

The fixed aerial homing system is essentially a simple method which enables the pilot to set the course of his aircraft directly towards a known wireless transmitter on the ground. It is particularly suitable for use on aircraft where no special wireless operator and/or navigator is carried and where the aircraft flies mainly on routes possessing no direction-finding station on the ground, but where ground communication or beacon transmitters are situated along the route, e.g. at the various aerodromes.

In this system use is made of a single-screened frame aerial, installed on the fuselage of the aircraft so that its plane lies at right angles to the line of flight of the aircraft, in addition to the normal fixed or trailing aerial used for ordinary reception. The coupling between the frame and open aerial is reversed by means of a three-position switch and is adjusted by means of a variable resistance, both of which are mounted in the D.F. panel.

In the central position of the reversing switch the frame aerial alone is connected to the receiver. In the left-hand position both the frame aerial and the open aerial are in use, while in the right-hand position both the frame aerial and the open aerial are in use, but with the phase of the coupling of the open aerial reversed.

If the aircraft is flying head on towards the transmitting station, no E.M.F. is induced in the frame aerial, and only the signal due to the open aerial will be heard when both open aerial and frame aerial are connected. Further, under these conditions, no difference will be observed whether the switch is moved either to the left or right.

If, however, the aircraft is not flying head on towards the transmitting station, an E.M.F. depending on the angle of divergence will be induced in the frame aerial. Now, on moving the switch from side to side the resultant signal strength will be greater if the open aerial coupling is coupled one way than it will be if it is reversed. From these indications it can be determined whether the transmitting station lies to port or starboard of the line of flight of the aircraft. By suitably correcting the course until no difference of signal can be detected, whichever way the open aerial is connected, the aircraft will be automatically "homed" towards the transmitting station. The accuracy of the course can be checked by putting the switch in the central position (connecting only the frame aerial) when, if the course is correct, no signals at all will be heard.

The adjustable resistance enables the signal strength due to the open aerial to be made approximately equal to the signal strength due to the frame aerial, thus enabling the greatest accuracy to be obtained during operation.

The rotatable frame aerial system provides full direction-finding service in cases where an operator and/or navigator is carried on large civil, military, or naval aircraft, and is particularly useful when flying over territory where no direction-finding stations are available, or over sea. The system enables the aircraft to "home" on a transmitting station as described above. and in addition, provides convenient means whereby

bearings may be taken on stations which lie off the normal course of the aircraft and from which the position of the aircraft may be determined by plotting, in the usual way, the bearings of two or more stations on a chart.

In this system a small rotatable screened frame aerial (Fig. 110) is used instead of the fixed frame aerial. The frame aerial is mounted externally on the aircraft fuselage and is rotatable from inside the aircraft by means of a hand wheel. The rotating mechanism incorporates a clutch so arranged that the frame is automatically locked in the desired position when the hand wheel is released.

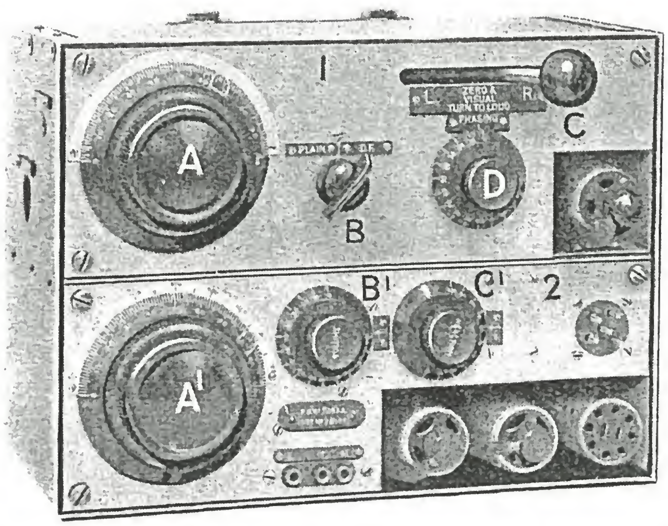


FIG. 112. MARCONI AIRCRAFT D.F. RECEIVER, TYPE A.D. 5062B

The method of taking bearings is similar to that already described under the "homing" system, so that if "homing" only is required it is only necessary to set the frame aerial at right angles to the line of flight of the aircraft, and to operate the reversing switch in the usual manner. In the case of bearings being taken on stations lying off the line of flight, the reversing switch is set in the central position and the frame rotated until no signal is heard from the transmitting station. The bearing of the desired station can then be read from a scale attached to the mechanism.

The indications for "homing" or for D.F. can be observed either aurally or, by the addition of an extra attachment, visually by means of a dashboard instrument (Fig. 113) which indicates by means of a needle the side off-course and also the true course to be flown. It is, therefore, possible once the aircraft has been set accurately on its course, for the pilot to fly to his destination using the dashboard instrument as a radio compass. When using the visual indicator, the hand-reversing switch is set in the middle position and a motor-driven reversing switch is used in its place.

THE FIXED FRAME AERIAL is a rigid screened frame which is mounted on the top of the fuselage or wherever convenient, at right angles to the line of flight of the aircraft.

THE ROTATABLE FRAME AERIAL is a rigid circular frame which is mounted outside the fuselage of the aircraft and operated from inside by means of a hand wheel. A drum and pointer indicates the angle at which the frame aerial is set in relation to the line of flight, and it is thus possible

to use the frame aerial for direction-finding purposes as well as for "homing." An automatic clutch in the frame mechanism locks the frame aerial in position as soon as rotation by hand is stopped.

The D.F. Receiver Type A.D. 5062B (Fig. 112)

This consists of a receiver panel and a D.F. panel in one box, the D.F. panel being in the upper compartment. The output from the frame aerial (fixed or rotatable), together with that from the open aerial (fixed or trailing), passes through a suitable transformer in the D.F. panel. The output side of this transformer is tuned and calibrated directly in metres, and forms the grid circuit of a H.F. pentode valve also carried on the panel.

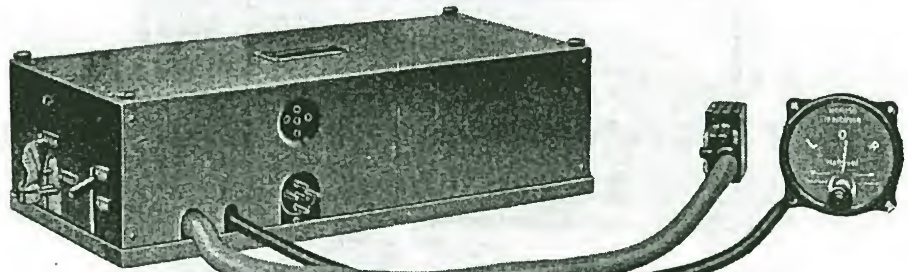


FIG. 113. ANODE CONVERTER VISUAL D.F. ATTACHMENT FOR USE WITH D.F. RECEIVER, TYPE A.D. 5062

On the panel are also mounted (*a*) a switch for reversing the phase of the coupling of the open aerial to the frame aerial, for giving off-course "homing" indications or for disconnecting it altogether if it is desired to use frame aerial D.F. reception or "homing" on the zero method, (*b*) an adjustable phasing resistance for adjusting the input from the open aerial, (*c*) a second switch which enables the operator to switch over from direction finding to normal reception on the open aerial. The D.F. panel also carries the waveband switch (2-way) and plugs and sockets for connecting to the frame aerial, to the open aerial, and to the receiver panel. The reversing switch is an integral part of the D.F. panel, and therefore no external hand-operated reversing switch is required.

The output of the D.F. panel passes to the receiver panel. This is a three-valve receiver using (*a*) a screened grid H.F. amplifier with tuned grid, (*b*) a detector with tuned grid and reaction, and (*c*) a three-electrode L.F. magnifier. The two tuned circuits are ganged to one dial which is calibrated directly in metres. C.W., I.C.W., or telephony can be received at will. A separate volume control is provided, and a two-way waveband switch is provided for selecting the waveband required.

THE VISUAL INDICATOR consists of a centre reading dashboard instrument, together with a rotating commutator reversing switch, which is driven either by a separate 12-volt motor or by the small anode converter which provides high-tension for reception. This switch reverses the open aerial coupling and also the input to the indicator, both reversals being in synchronism. If the visual indicator is in use, the hand-reversing switch on the D.F. panel should be set in the middle position, but if desired aural indications can be checked from time to time by operating the hand reversing switch without stopping the commutator switch. The addition of the visual indicator attachment turns the D.F. equipment into what is often known as a "radio compass."

The power supply is from the 12-volt accumulator belonging to the

aircraft. The low-tension filament supply is approximately 1·3 amperes at 12 volts and the high-tension supply is approximately 20 milliamperes at 200 volts. The high-tension is derived from an anode converter driven from the 12-volt accumulator and taking an input of approximately 2 amperes. The total load on the accumulator during reception is therefore

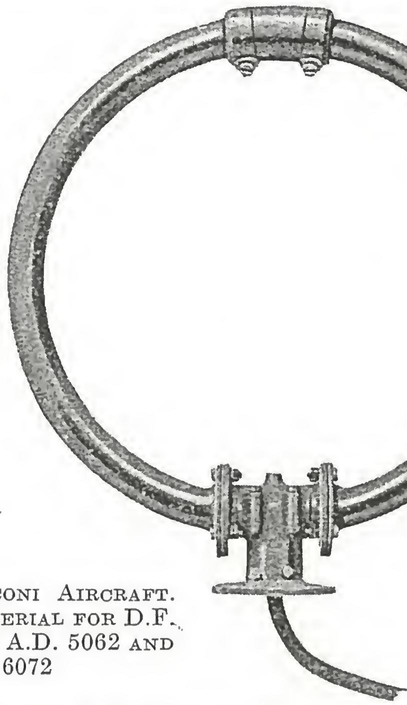


FIG. 114. MARCONI AIRCRAFT. 13″ D.F. LOOP AERIAL FOR D.F. RECEIVER TYPE A.D. 5062 AND A.D. 6072

3·3 amperes. If the D.F. receiver is used in conjunction with a wind-driven generator powered transmitting equipment, the high-tension will of course be derived from the wind-driven generator instead of from the anode converter, and a separate 12-volt motor will be used for driving the visual indicator.

The approximate overall dimensions and weights of the various items of the equipment are as follows—

Receiver Type A.D. 5062B—
- Height, 8½ in. (21·6 cm.)
- Width, 11½ in. (29·2 cm.)
- Depth, 6 in. (15·2 cm.)
- Weight, 14 lb. (6·35 kg.)

Fixed Frame Aerial—
- Overall diameter, 13 in. (33 cm.)
- Overall height above fuselage, 14½ in. (37 cm.)
- Weight, 3 lb. 4 oz. (1·46 kg.)

Rotatable Frame Aerial
- Overall diameter, 13 in. (33 cm.)
- Overall height above fuselage, 16 in. (40·64 cm.)
- Weight, 11 lb. (5 kg.)

Visual Indicator (Dashboard)—
- Overall diameter, 3½ in. (9 cm.)
- Weight, 1 lb. 1 oz. (0·45 kg.)
- Depth of case behind panel, $1\frac{7}{16}$ in. (3·65 cm.)
- Overall depth behind panel including studs, 2½ in. (6·35 cm.)

Visual D.F. Motor Switch Unit Type 626A—
Height, 4$\frac{5}{8}$ in. (11·74 cm.)
Width, 6 in. (15·2 cm.)
Length, 12$\frac{1}{16}$ in. (30·6 cm.)
Weight, 10 lb. 10 oz. (4·75 kg.)

Visual D.F. Anode Convertor Switch Unit Type 626B—
Height, 4$\frac{5}{8}$ in. (11·74 cm.)
Width, 7 in. (17·78 cm.)
Length, 15 in. (38·0 cm.)
Weight, 16 lb. 14 oz. (7·64 kg.)

Trailing Aerial Equipment (Complete)—
Weight, 11 lb. (5 kg.)

Fixed Aerial Equipment (Complete)—
Weight, 4 lb. (1·8 kg.)

The total weight of the D.F. receiver complete is therefore approximately—

(*a*) with $\left\{\begin{array}{l}\text{rotatable frame aerial}\\ \text{trailing aerial}\\ \text{visual indicator type 626B}\end{array}\right\}$. 57 lb. (26 kg.)

(*b*) with $\left\{\begin{array}{l}\text{rotatable frame aerial}\\ \text{fixed aerial}\\ \text{visual indicator type 626B}\end{array}\right\}$. 50 lb. (22·7 kg.)

(*c*) with $\left\{\begin{array}{l}\text{fixed frame aerial instead}\\ \text{of rotatable frame aerial}\\ \text{these weights will be}\end{array}\right\}$. 48 lb. (21·8 kg.) or 41 lb. (18·6 kg.) respectively.

The above weights do not include the weight of the 12-volt aircraft accumulator.

If this D.F. equipment is used in conjunction with a normal Marconi type A.D. 49/50 medium wave transmitting and receiving equipment, the A.D. 5062B D.F. receiver would replace the A.D. 50 receiver, and the power supply and open aerial would already be available in the aircraft. The addition of full D.F. with visual indication could therefore be made to the A.D. 49/50 equipment for an additional weight of approximately 30 lb. (13·6 kg.). If homing only is required, the additional weight is approximately 21 lb. (9·5 kg.).

4th Method. A new system of directional wireless communication with aircraft in flight, originally developed in Germany and now in the experimental stage in this country, appears to have achieved highly satisfactory results and to promise interesting and useful developments. This system, of which the pioneers are Lorenz and Telefunken, is in no sense a navigational system, but is one designed entirely with the object of enabling aircraft to make safe landings on aerodromes enveloped in more or less local fog. Two special extra short-wave receivers are required in the aircraft, in addition to one arranged to work on the ordinary wave-length. Three special extra short-wave ground transmitters complete the equipment. All tuning arrangements are fixed, and the sets are relatively simple and cheap.

The operation of the system is based on the phenomenon associated with ultra short waves of following a straight line, so that two stations which are not in sight of each other cannot communicate or interfere with each other. This fact, of course, permits stations separated by quite short distances—25 to 30 miles or so—to use identical equipment. At present a waveband of 7 to 20 metres is utilized for the new system, and when it is remembered that there is a difference of 4$\frac{1}{2}$ million cycles between wavelengths of 8 and 9 metres it will be appreciated that the risk of interference

is very small. The fact that these ultra short waves are reflected by the Heaviside Layer, and come down again to earth at great distances from the transmitter has no significance as far as the choice of these waves for the particular purpose in mind is concerned. The operation of the Lorenz and Telefunken systems in Germany, however, is accompanied by the formation of two approach paths to the aerodrome, one at 180° to the other, whilst the efforts of the Marconi Co., in this country, are directed towards the development of a similar system in general, but characterized by an elimination of back radiation and therefore the production of only a single path of approach to the aerodrome.

A fact which is vitally important to the successful operation of the system is the ease with which the "fields of strength" set up by the ultra short-wave transmitting aerial can be deformed to an accurate and controlled extent, by means of earthed reflectors, or by the earth itself.

In practice the three ground transmitters are located (*a*) at the far end of the best landing run for the particular aerodrome. This is the main transmitter and operates on 9 metres. It controls both vertical and horizontal navigation in approach and landing, (*b*) at the boundary of the aerodrome, on the line of approach. This transmitter operates on 7·9 metres and throws a vertical fan of signals upwards, designed to warn the pilot that he is crossing the boundary of the aerodrome, and (*c*) approximately two to three miles away from the boundary of the aerodrome, and on the line of approach.

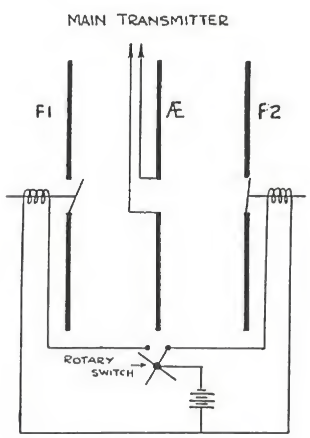


Fig. 115

This transmitter also operates on 7·9 metres and also throws a vertical fan of signals upwards, designed to give the pilot his first warning that he is approaching the aerodrome and is approximately two to three miles away from it.

At the main transmitter the aerial takes the form of two vertical rods, each only a few feet long, mounted vertically end to end and one above the other, with a gap between them. On each side of this aerial and about ten feet away from it, are dummy aerials, or "reflectors." These dummy aerials are also divided at their middles, but can be made electrically continuous by means of mechanically operated switches which short circuit the gap at the middle. With the switches closed, the dummy aerials act as "reflectors" or "field deformers," but with the switches open they have no effect (Fig. 115).

The purpose of the "field deformers" is so to distort the field as to produce in the aircraft a series of signals which indicate to the pilot his correct flight path.

The normal field of stress surrounding an aerial system consists of a series of concentric hemispheres having the ground line as a common diameter.

In Fig. 116 the dotted circle is the plan view of the field spreading out with equal strength from all round the aerial at *A*. The full line oval is the deformed field produced by the influence of the "field deformer" *F*.

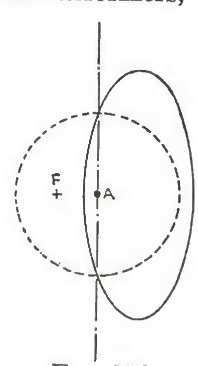


Fig. 116

In Fig. 117 the two ovals show the alternative positions taken up by the deformed field by using the "field deformers" at *F* 1 and *F* 2 alternatively. It will be noted that the two deformations have certain common points at the

intersections of the loops. An observer stationed anywhere along the line joining these two points of intersection of the loops will receive signals with equal strength from either loop, but if he is placed to one side of the line he will receive signals from one loop with greater strength than he will receive those from the other loop. If the rotary time switch operating the switches at the mid points of the field deformers is so arranged that one deformer is in operation for an appreciably longer period than the other, an indication can be conveyed to the observer to tell him whether he is to the right or the left of the line. On the one side of it he will receive signals which are a series of dashes, whilst to the other side he will hear a series of dots. If placed on the line he will hear a continuous and uniform note, since the dots and dashes will merge to produce that result. (See Fig. 118.)

It should be noted that the loops are not true ovals, but are considerably flattened on their inner sides. This phenomenon ensures that the position of the path of equal strength—the landing path—is very clearly and accurately defined.

Having considered the deformed field in plan, it is necessary to consider it also in section.

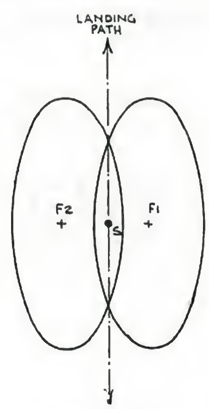


FIG. 117

Fig. 119 shows the shape of a vertical section of the deformed field as seen from one side of the path of approach.

It will be noted that whereas the field produced by medium wave-length emanations is roughly hemispherical, that produced by the ultra short waves chosen is repelled by the earth and results in the shape shown, which is a section in the plane of the landing path. The lower portion of this diagram is reproduced in Fig. 120, and the two subsidiary transmitters have been indicated. The aerials of these transmitters are arranged horizontally so that a broad flat fan of signals is thrown vertically into the air.

An aircraft approaching in fog at, say, 1,200 ft., picks up the first signals at about fifteen miles from the aerodrome, or at nearly forty miles if it is flying at 3,000 ft. The first signals are probably a series of dots or a series of dashes and the pilot must turn to right or left until the signal note becomes continuous.

A dashboard instrument is provided, the needle of which deflects to right or left in response to the dots or dashes.

The pilot then turns in on the line of approach, keeps his craft on its course by maintaining a continuous signal note, or a steady needle in its vertical position, and maintains a steady height of approximately 1,500ft. This manœuvre will settle him on his true approach course. As he passes through the field of the most distant ground transmitter a neon bulb in the cockpit is illuminated

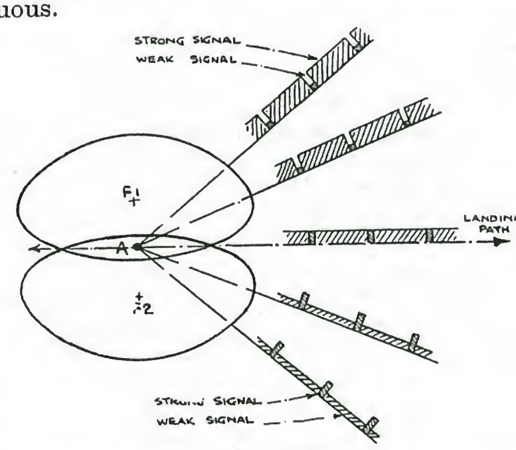


FIG. 118

for a second or two and indicates the exact distance of the aircraft from the boundary of the aerodrome, and that it is time to throttle back.

The aircraft is then put into a natural glide, and direction is maintained by the continuous signal from the main transmitter. At a later stage a

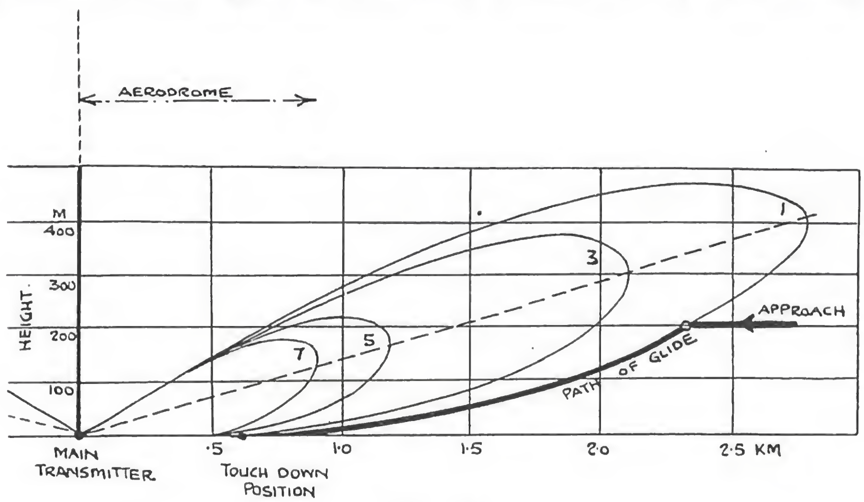


FIG. 119

second neon light is illuminated for a second or two and indicates that the aircraft is passing over the boundary of the aerodrome. The main transmitter provides for control of the glide in, including the holding off stage and the final touch down.

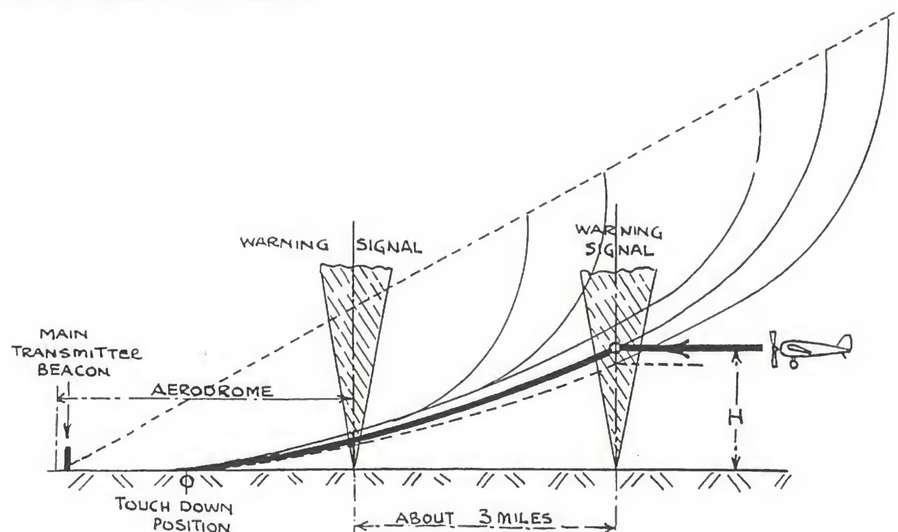


FIG. 120

It will be noted from Fig. 120 that the lines of equal field intensity are crowded close together at the aerial and gradually separate as they travel outwards. The pilot is also provided with a dashboard instrument which indicates the intensity of the field. During the time of approach this instrument will indicate a rapidly strengthening field, since the aircraft is cutting the lines of equal intensity and is approaching the centre

of disturbance. The moment the pilot sees the second neon lamp go out, however, he knows that he has arrived over the boundary of the aerodrome and by minor movements of the elevator he endeavours to keep the reading of this instrument at a constant value. In doing this he causes the aircraft to travel down the particular curved path which the machine picked up at the moment of final reading.

The shape of the distorted field is very similar to the ideal landing path of an aircraft and provides for the glide, holding off, and touch down. It also provides a wide range of paths to choose from, so that the characteristics of any particular machine can be easily catered for. Whilst all lines converge on the aerial, two lines which are only six inches apart over the aerodrome may be two to three thousand feet apart over the first approach beacon. An error of a few inches in height at the hold-off stage will show a violent deviation on the instrument.

The undermentioned types of direction-finding equipment are at present officially approved for use on civil aircraft.

DIRECTION-FINDING EQUIPMENT

Set	Type	D.F. Range in Metres
Marconi's Wireless Telegraph Co. Ltd.		
A.D.16	D.F. receiver	600–1,600
A.D.32A	D.F. attachment	500–1,000
A.D.32D	D.F. attachment	500–1,600
A.D.35A	D.F. receiver	550–1,550
A.D.52A	D.F. attachment	500–1,000
A.D.52B	D.F. attachment	500–1,600 (in two ranges)
A.D.52C	D.F. attachment	500–1,550
A.D.52D	D.F. attachment	500–1,550 (in two ranges)
A.D.5062A	D.F. receiver	600–1,200
A.D.5062B	D.F. receiver	600–1,550 (in two ranges)
A.D.5872A	D.F. receiver	600–2,000 (in two ranges)
A.D.5872B	D.F. receiver	600–2,000 (in two ranges)

BONDING

The close proximity to the radio installation of a high-tension ignition system results in severe electrical disturbances which must be eliminated before the operation of a sensitive receiving system can be made feasible. Furthermore, the vibration of various parts of the machine may be responsible for very troublesome electrical noises in the receiver unless proper precautions are taken. In order to avoid these difficulties it is necessary to resort to electrical bonding of the aeroplane and the complete electrical shielding of the wiring systems and electrical equipment.

Bonding designates the interconnection of all metal parts of the aeroplane in such a manner as to afford between such parts paths of small resistance to the flow of high frequency currents. Charges of atmospheric electricity tend to accumulate on metal parts which are separated from the frame of the machine by high resistance paths. If these paths vary in resistance due to vibration, rubbing, etc., the charges will flow off in an irregular manner, thereby setting up electrical disturbances. If the resistance of the paths is quite high, charges may accumulate until the potential of the isolated part becomes so high that a spark will jump to an adjacent conductor. This not only results in severe radio noise but

constitutes a serious fire hazard. Another point which must be taken into account is the fact that the metal framework of the machine is used as the "Ground" or counterpoise for the radio equipment. For this reason it is important to have this framework interconnected with all other parts of the plane so as to make this counterpoise as extensive as possible. Because of this feature it is necessary to furnish wooden planes with a metal network running through all parts of the machine. Wooden struts, longerons, etc., are metallized by the use of metal strips fastened longitudinally along such parts and connected together to form a continuous network.

Wooden wings are metallized and bonded in the following manner. A metal strip $\frac{1}{4}$ in. $\times$ $\frac{1}{64}$ in. or larger shall be fastened along the front and rear spars from fuselage to wing tips. These strips shall be interconnected to the "Earth," to the internal brace wires at each drag brace, to the external brace wires and fittings wherever these wires and fittings come into the wing, and to each other by similar strips which run from front to rear spars along each drag brace. The front and rear strips shall also be connected together at the wing tip. If the wing carries a metal leading edge the front metallized strips may be dispensed with and connection made to the edge. The same is true of any metal wires or sheets, in the trailing edge or other parts of the wing, which are of sufficient size to be used in place of the metallized strip. The metal shielding which covers any electrical wires in the wings such as landing light leads, etc., shall be earthed at least every 14 in. to 20 in. to the metallizing strips and at each drag brace.

Wherever control or brace wires, or other movable or semi-movable parts come into casual contact with each other, or with other metal parts of the plane, it is necessary either to furnish insulation at the point of uncertain contact or else to bond the parts together. Crossed wires may be insulated from each other by passing one wire through a hole at one side of a flat insulating washer and the other through a similar hole in the opposite side of the same washer. Small button or egg type insulators (such as micarta spacer wrapped with tape) may be used to hold the wires apart instead of the washer. This method of insulating the wires where they cross is to be preferred to bonding by means of a soldered lead as the flux used in soldering has a corrosive action.

It has been found that turnbuckles and tie rod terminals sometimes offer considerable resistance to the flow of high frequency currents. Such equipment should therefore be tested with the circuit tester described below and wherever a high resistance is found it should be by-passed by a copper bond.

A wooden fuselage is to be bonded and metallized as follows: A metal strip equivalent to that used in the wings is to be fastened along each longeron. This strip shall extend from the engine to the tail surface making good electrical contact with the engine base and with each metal part and fitting along its length, branch strips being used if necessary. These longeron strips must also be connected to the wing strips. All water, gasoline and oil lines should be earthed to the frame at frequent intervals. Rubber hose joints should be by-passed by copper braid bonds.

The metal hinges of rudder, elevators, ailerons, etc., must be bonded across and the control wires attached to such parts must be bonded to the hinges. The whole is to be connected to "Earth," which means making one electrical circuit of all metal parts.

The method generally used is to place braid about 2 in. wide on the control wires near the thimble and wrap with waxed and shellaced cord, then pigtail length of braid to an effective "earth" contact. If soldering

is attempted, it must be done with due care on account of possibility of weakening control wires.

In metal aeroplane metallizing strips are, of course, unnecessary, but it is quite essential that the various parts of the aeroplane be connected by low resistance paths and a certain amount of bonding will sometimes be required in order to achieve this. The resistance between metal parts which are in contact may be rendered high by a protective shellac or other coating or by oxide films. Contact surfaces between each of the parts should be scraped bright and clean and after having been forced into tight contact a new protective coating applied along the outside of the joint. Wherever there is any uncertainty as to a satisfactory connection at a contact it should be by-passed by a copper bond. Parts that are welded together need no attention as welded joints are of low resistance. Lighting wires which are shielded should be bonded every 14 in. to 20 in.

The final test of the efficacy of bonding and shielding together can be made only by noting in the receiver the degree of electrical noise with the machine in actual flight. However, for purposes of maintenance, inspection, and fault finding, it will be quite helpful to employ tests as follows: A circuit tester consisting of a battery, ammeter and series resistance, adjusted to carry 2 amperes at least, is used to determine whether there is a low direct current resistance between adjacent parts. Contact is conveniently made to the parts by the use of stout, sharp pointed electrodes. When one electrode is placed on either side of a joint, the ammeter should read at least 2 amperes. If the reading is irregular or absent it is a sure indication that the resistance of a joint is too high. Head telephones are not to be used in making tests of this type. All bonding and joints throughout the metal framework of the plane should be tested in this way.

Shielding

Whenever a spark discharge occurs in an electrical circuit, high frequency oscillations are set up and create an electro-magnetic effect which is appreciable at some distance from the circuit. If the discharge is highly damped as in the case of spark ignition circuits, the oscillations involve a very wide range of frequencies and a tuned radio receiving set will pick out and amplify those frequencies to which it is resonant. Consequently the ignition circuit can be responsible for a prohibitive amount of noise in the receivers. In order to eliminate this it is necessary to completely enclose the high-tension circuit in a continuous metal sheath, or shielding, which makes good contact with the aeroplane frame at points 14 in. to 20 in. apart. When such a shield is properly installed, the electromagnetic effect of the oscillations is practically eliminated from the space outside of the sheath.

The low-tension wire systems on the plane may also be responsible for radio noise. Radio frequency interference from sparks at the commutator of the generator may be transmitted along the low-tension systems and unless the wires of this system are effectively shielded, this interference will be audible in the receiver. Furthermore, unshielded lighting and instrument wires may pick up high frequency energy from the ignition or generator circuit due to the fact that the shielding of these circuits is never perfect. This energy is then distributed over the whole low-tension wiring system and may cause serious trouble. Consequently, the only satisfactory practice is to completely shield *all* wires on the machine. In addition a 4 mf. condenser across the regulator and also a tin cover for the generator field lead on the voltage regulator will eliminate noise from these sources.

The high-tension system is shielded as follows—

The magnetos are to be completely enclosed in metal housings. The majority of magnetos on the market have metal housings with openings in them which may or may not be covered by insulating material such as bakelite plugs. In such cases it is necessary, and usually sufficient, to cover the openings with sheet metal so formed as to make firm contact with the housing at several points. One company has developed a completely shielded magneto especially designed to eliminate the disturbances arising inside the magneto housing and to facilitate the earthing to this housing of the shielding on the leads. These magnetos are now available

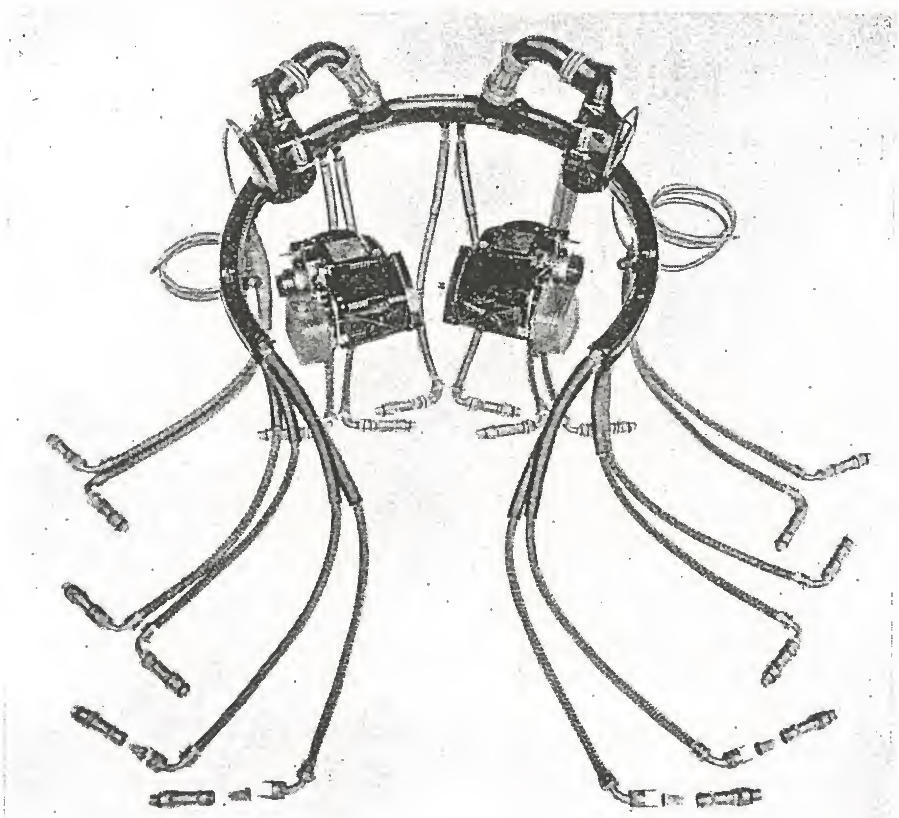


FIG. 121. SHIELDED MAGNETOS AND IGNITION LEAD HARNESS

to the public. This company also furnishes tins to be used with the semi-shielded magnetos.

The leads from the magnetos are to be enclosed in a continuous metal sheath. These are now made available by manufacturers in the form of ignition harnesses, provided with woven shielded auxiliary leads which may be used on various types of motors. (Fig. 121.)

There are available complete ignition harnesses which are encased in flexible braid. If such a harness is employed, it is advisable to run it through a pipe manifold because of the increased mechanical protection. In such a case it is not necessary to solder the braid to the pipe since the braid sheath is continuous. There has recently been placed on the market

a shielded high-tension cable which enables those familiar with the requirements of adequate ignition shielding to construct their own ignition harness.

Where the wires emerge from the magneto housings the braid shielding is to be fastened to the housings at the point of entrance. Frequently such leads emerge through an insulating block and, as mentioned above, this block should be covered with a sheet metal cover. It is advisable to solder the braid to this cover all round the hole through which the wires emerge.

The braiding or pipe should make contact with the engine metal at as many points as may be convenient. Contact is to be made by short pigtails or wires which are bolted or soldered to the framework of the engine. Unless such pigtails have been woven as an integral part of the braid, they must be soldered to the shielding. Great care should be taken not to injure the insulation of the wiring either by heat or by the corrosive action of soldering flux. An alternative to soldering a connection to the shielding is to lay the pigtail or wire along the shield and wrap tightly with No. 20 bare soft copper wire.

The origin of the most severe disturbances due to the ignition circuits is at the spark plug itself, and it is quite essential that this plug be shielded completely. Make-shift attempts at shielding of this part may result in incomplete elimination of interference, in overheating of the plugs, short-circuiting the ignition system and general unsatisfactory operation. Shielded plugs have been designed especially for use on radio equipped aircraft and these have proved satisfactory through an extended period of operation on many leading airlines. For those operators who prefer to use a standard unshielded plug, there are available many styles of shielded covers for plugs which have been designed to effectively suppress interferences arising from the plugs.

As has been stated above, it is quite essential to enclose all low-tension wires in braided cable. The battery itself must be enclosed in a metal box, if required by the regulations, this box being earthed by short leads to the frame of the aircraft. All braiding should be run as close to the terminals of the wires as is possible without creating the danger of a short-circuit. Earth connections should be made as near to all terminals as may be consistent with minimum length of ground leads. It is also necessary to earth the shielding to metallizing strips or to the "Earth" at intervals of 14 in. to 20 in.

A bonding strip must be installed along the back of the instrument board. This strip is to be connected to each longeron, in a metal plane, or to the longeron bonding strips in a wooden plane. The metal cases of all instruments on the board are to be connected to the bonding strip. The metallic lines, tubes and wire shielding shall also be connected to this strip and such lines, etc., shall be earthed at intervals of 14 in. to 20 in. It is also desirable that metal covers be provided for all switches and instruments connected in the low voltage circuits.

If a metal instrument board is used, the bonding strip may be dispensed with. The board is connected to the longeron bonding system and the various connections mentioned above are made to the board. Care must be taken to see that all contacts at the connections are clean and firm.

The majority of engines used at present are fired by magneto ignition systems to which the above directions specifically apply. With installations employing coil ignition it is advisable to follow the same general principles and shield *all* wiring present. It is sometimes believed that this is not necessary, but unless complete shielding is used it will often be found impossible to obtain satisfactory reception with a high gain receiver.

The efficacy of shielding can be determined only by operating the radio

receiver with the aeroplane in flight. In many cases proper shielding will completely eliminate electrical noise from the receiving set, but in no case should there be a residual noise greater than a very faint hum in the telephones. The test should be made under the following conditions.

(1) Both the receiver and the transmitter of the radio set shall be completely installed and connected up.

(2) The aeroplane shall be in flight, the engine running at cruising speed.

(3) The receiver shall be adjusted for maximum gain and tuned for maximum response to a weak incoming signal.

(4) The main L.T. switch to the wireless shall be in the "On" position.

(5) Both ignition switches shall be on.

(6) All other electrical equipment of the aeroplane shall be operating.

There have been no methods devised for predetermining the efficiency of the shielding. Preliminary checks may be made while the engine is running on the ground. It will be noted in many cases that the disturbance is very loud on the ground, due to the vibration of the aeroplane, but becomes negligible in actual flight. The best assurance that the shielding will function properly is obtained by meeting the following three requirements—

(1) All electrical apparatus and conductors must be shielded.

(2) All shielding must be earthed at frequent intervals.

(3) All contacts between metal parts of the machine must be extremely low in resistance.

The bonding and shielding require frequent inspection in order to ensure that the numerous contacts and connections are in good condition. Because of the constant vibration, broken leads and open earth connections are likely to be of common occurrence. It often happens that a single open circuit or high resistance may be responsible for loud noises in the radio receiver. The tracing down of such trouble usually requires a considerable amount of care and patience and involves systematic checking of the bonding and shielding throughout the machine. The details of this check will, of course, vary somewhat with the aeroplanes and installations under consideration, but the procedure should be such as to ascertain whether the fundamental requirements outlined in the foregoing specifications have been fulfilled.

A regularly made inspection of the electric cables, bonding and earth connections in the aeroplane will minimize the possibility of circuit trouble due to loose contacts or broken leads. Poor earth connections reduce the effectiveness of shielding and are the cause of the greatest part of noise interference. Both the ignition system and lighting circuits in the aeroplane as well as all circuits associated with the radio equipment should receive careful attention in this respect. A gradual increase of noise level from day to day can be almost always attributed directly or indirectly to some defect of this nature in the shielding system.

Frequently the source of this noise can be located by means of a small antenna used in conjunction with one of the radio receivers. Such an antenna consists of a length of flexible wire shielded its entire length except for a distance of approximately a foot at one end. The opposite end is connected to the input of the radio receiver and the shield at this end earthed to the receiver mounting. By probing with the unshielded portion of the wire the source of disturbance can frequently be localized.

It should be made certain that the following conditions are fulfilled—

(1) The bonding must be adequate.

(*a*) The resistance of all joints between metal parts and across bonds should be checked with a circuit tester.

(*b*) See that all hinges, brace wire and control wire terminals, turn-buckles, etc., are properly by-passed by bonds.

(*c*) The leads which bond isolated parts to the frame must be as short as possible.

(*d*) All pipe lines, instrument cases, shielding, oil and petrol tanks, conduit, etc., must be earthed by leads which are as short as possible and extended conductors, such as shields, etc., must be earthed at intervals of not more than 14 in. to 20 in. If there is any possibility of trouble due to inadequate earthing, add additional bonding and see if improvement results.

(2) The shielding must be complete.

(*a*) See that all wiring is shielded and that the shielding is free from high resistance joints. At the terminals of wires the shielding is to be brought as close to the end of the conductors as is consistent with safety. Where a wire passes through a metal surface the shield must be bonded to that surface all around the hole through which the wire passes, or be thoroughly insulated from this surface.

(*b*) See that adequately shielded spark plugs are used and that the braid covering the high-tension leads makes good contact with the metal shield on the plug.

(3) There must be no accidental contacts between sliding or vibrating parts. See that all such parts are either insulated at point of contact or are properly bonded.

CONCLUSIONS

In conclusion, it is desirable to utter a word of warning in connection with the installation of electrical and/or wireless installations in aircraft, or the incorporation of modifications of these systems, since such action might invalidate the aircraft's Certificate of Airworthiness. The following official requirements must be borne in mind—

1. All wireless apparatus and accessories used on aircraft must be approved as regards design.
2. All wireless apparatus and accessories installed in aircraft must be certified (release note) as being constructed and tested in accordance with approved designs.
3. The installation drawings, showing the position and methods of installation of each piece of apparatus and of the wiring in the aircraft, must be similarly approved.
4. Installation work, or work in connection with the modification of an installation, and the inspection and testing thereof, must be carried out by, or under the direct supervision of, a duly qualified ground engineer, or contractor officially approved for such work.
5. The necessary log book entries are made and certified, and any necessary action taken to obtain an official amendment of the aircraft's current Certificate of Airworthiness.

In connection with the above, it may be of interest to note that direct application to the Air Ministry for approval of electrical and wireless apparatus and accessories, or of proposed installations, or modification of existing installations, is not always necessary before proceeding with the work, since the Ministry is prepared to accept certificates by duly authorized representatives of certain firms who have been officially approved for the design of apparatus, design of installation, work of installation, or the inspection and test of installation.

Finally, special attention is directed to the requirements of the following Air Ministry Notices to Aircraft Owners and Ground Engineers—

No. 35 *of* 1936: "Airworthiness Approval Procedure for Instruments and Equipment."

No. 9 *of* 1937: "Civil Specification Memorandum No. 4—Lists of Approved Firms."

No. 6 *of* 1939: "Approval of Radio Communication Apparatus and its Installation in Aircraft."

No. 7 *of* 1939: "Ground Engineers Licensed in Category 'A'—Duties as Regards Compasses, Turn Indicators, and Electrical Services."

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INSTRUMENTS

REPAIR, OVERHAUL, TESTING, AND CALIBRATION
OF AIRCRAFT AND AERO-ENGINE INSTRUMENTS;
ADJUSTMENT, INSTALLATION, AND COMPENSATION
OF COMPASSES IN AIRCRAFT

CATEGORY "X" LICENCE

BY

R. W. SLOLEY

M.A. (CAMB.), B.SC. (LOND.)

CONTENTS

APPENDICES

*The sections marked with an asterisk are not essential for the ground engineer, but have been included to meet demands for information which is not readily accessible elsewhere.

ILLUSTRATIONS

INTRODUCTION

In recent years aircraft instruments have assumed an importance which was hardly anticipated in the early days of aeronautics. A pilot's attention was then wholly occupied in the control of his machine during flights, which were undertaken only in good weather conditions, and even then were of no great length. Training was rightly directed to teaching a pupil to trust to his sense-impressions alone, and to judge of the attitude and behaviour of his machine by the use of his ears and eyes and by what is called the "feel" of the machine. Instruments were few, crude, and unreliable, and a certain distrust of them existed. The impression that instruments are generally unreliable persists in some circles even to this day.

The progress in aviation, as longer cross-country flights as well as flights over water were undertaken, led to the need not only for a greater range of instruments, but for instruments of a more reliable type. When aviation became possible in all types of weather, fair or adverse, the new conditions demanded improved forms of instruments in order that the pilot might supplement his sense-impressions by the indications of his instruments.

It is owing largely to the enterprise of British instrument firms that British aircraft instruments rank among the best to be obtained anywhere in the world. The present stage of development has been reached only after much costly research work. The standard of workmanship and accuracy is now such that it is possible for a pilot to rely on the indications of his instruments when flying at night or in foggy weather. During training a special period is usually allotted to "blind flying," as it is termed, that is, flying by instruments alone, under a hood which prevents the pupil from seeing the horizon and external objects.

Considering the standard of accuracy which has been reached, aircraft instruments are remarkably robust, but it is only gradually being realized that they require and deserve careful handling, and that attention given to installation and maintenance will result in more satisfactory service and longer life. Owing to the relatively severe conditions under which they are used their life is shorter than that of instruments used under ordinary land conditions. It is highly desirable, therefore, that all instruments should be checked periodically for accuracy of calibration, and not allowed to remain in regular use until a defect becomes obvious.

This book has been written with a view to providing the ground engineer with such information as will enable him to carry out his duties so far as they concern instruments, and to get the best possible service from those instruments.

The book is not a treatise on aircraft instruments in general, and the instruments described have been restricted mainly to those which have already been approved by the Air Ministry for use on civil aircraft. Some are obsolescent, but these as well as other types have been included because they illustrate the general principles involved, and the ground engineer is likely to meet with them in the course of his duties.

The writer desires to acknowledge his indebtedness to various aircraft instrument manufacturers who have kindly provided information concerning their instruments and photographs for reproduction, and to his

colleague, Mr. C. E. Dodge, for assistance with Section 8, Appendix X, and in the preparation of the diagrams.

THE DUTIES OF THE GROUND ENGINEER

The ground engineer is required to see that the instruments fitted are of the approved types or comply with the approved specifications, and that they have been duly inspected and approved for calibration, and are in serviceable condition. He must verify that they are correctly fitted in accordance with the installation diagrams and directions. At any time he may be called upon to decide whether an instrument is or is not in a fit condition to be used in the aircraft.

The aim of this book is to assist the reader to prepare himself for this work, which requires knowledge of the methods of inspecting and testing the installation of instruments to ensure correct functioning, and experience in the repair, overhaul, testing, and calibration of the various types of instrument. It is assumed that the reader has a fair knowledge of mechanics and physics, especially of thephysics of the atmosphere, and the elementary phenomena of magnetism, which is requisite for the study of compasses. To obtain a certificate in category "X," training in an instrument workshop and experience in a recognized test laboratory are essential. A useful knowledge cannot be gained merely by reading descriptions of the mechanism or studying diagrams in books.

PROBLEMS OF DESIGN

It should be realized that aircraft instruments present a number of special problems to the designer, and some of these will be mentioned in order that the reader may appreciate their importance and bear them in mind while studying particular types. The following conditions must be satisfied in order to ensure correct functioning. They may be regarded as essential features of design—

1. Instruments must be robust in order that they may withstand the vibrations experienced in flight and the shocks of taxi-ing over the ground and of landing.

2. They must not be unduly heavy. Every extra ounce of weight carried is said to add approximately 6s. to the cost of an aircraft. They must be compact in order to occupy the minimum amount of space.

3. The moving parts must be balanced and as light as possible, in order to reduce errors due to tilting, as well as to avoid inertia effects when the aircraft is increasing or decreasing speed.

4. The friction at the bearings must be reduced to a minimum. A slight amount of friction, however, will be overcome by the normal vibration of the instrument panel, and therefore it is permissible to tap slightly instruments under test before taking a reading.

5. Suitable damping of the moving mechanism must be provided, in order that the pointer may take up its position quickly and give a steady reading.

6. The natural vibration period of the moving parts must not bear a simple relation to the natural frequency of vibration of the engine, otherwise its pointer may oscillate violently, making it impossible to obtain a steady reading.

7. The case of the instrument must effectively exclude dust and moisture.

8. The dial must be clearly marked to permit of easy reading by day or, when illuminated, by night. Attention must be given to the dimensions and spacing of the marks to avoid any uncertainty as to the actual reading.

9. The indications of the instrument must be reasonably correct, whatever position is assumed by the aircraft.

10. The readings must not be affected unduly by such changes of temperature as are normally experienced. Some form of automatic compensating mechanism is usually incorporated in the design.

11. The materials must be chosen so as to provide the maximum resistance to corrosion.

12. Instruments must be easy to install and to remove for adjustment or replacement.

CLASSIFICATION OF INSTRUMENTS

The principal instruments used in aircraft may be conveniently classified as follows—

A. Engine Performance Instruments.

1. The Engine Speed Indicator.
2. The Fuel Pressure Gauge.
3. The Oil Pressure Gauge.
4. The Boost Gauge.
5. The Oil Temperature Thermometer.
6. The Radiator Thermometer.

B. Aircraft Performance Instruments.

7. The Air Speed Indicator.
8. Inclinometers. The Cross Level. The Fore-and-aft Level.
9. The Altimeter or Height Indicator.

C. Navigational Instruments.

10. The Turn Indicator.
11. The Compass.
12. The Watch.

Other instruments may be used for special purposes, e.g. the Fuel Flow Indicator, the Fuel Tank Contents Gauge, the Statoscope, and the Rate of Climb Indicator.

Four of the above types of instruments are obligatory for all civil aircraft working under ordinary conditions—

1. The Engine Speed Indicator.
2. The Air Speed Indicator.
3. The Altimeter.
4. Pressure Gauges as necessary.

A compass and a watch are essential for aircraft carrying passengers or goods for hire or reward for flights extending beyond a radius of twenty miles from the point of departure. A turn indicator is necessary when there are more than five seats in the aircraft.

The Air Navigation Directions, 1936 (A.N.D. 13), give particulars of the conditions under which instruments must be carried by aircraft. The approval of the Air Ministry is necessary for the method of installation adopted for an instrument which is a fixture in the aircraft.

Since the first edition of this book was published, Civil Specifications for certain instruments (see p. xii) have been issued. Instruments must comply with these specifications before approval for their use can be given.

In the case of these instruments, approved types are no longer specified by name.

1. Altimeters.
2. Air Speed Indicators.
3. Pressure Head for use with Air Speed Indicators.
4A. Engine Speed Indicators.
5. Pressure Gauges for Oil and Fuel Systems.
6. Oil Temperature Thermometers.
7. Radiator Temperature Thermometers.
8. Turn Indicator.
9. Pilot's Magnetic Compass.

These specifications are given in Appendix XI.

Before any new instrument of these types can be installed in an aircraft, a certificate from an approved testing authority must be produced. This must certify that the instrument complies with the appropriate specification. Certain firms are authorized to issue certificates in respect of their own products. Otherwise, a certificate issued by an approved test house is necessary.

In the case of instruments for which a specification has not been issued, or is not applicable, approval of the Air Ministry must be obtained before use.

Types of instruments already approved by the Air Ministry before the issue of the specifications mentioned above may continue to be used until further notice.

For further information as to the conditions of approval, the reader is referred to the *Airworthiness Handbook of Civil Aircraft*, Vol. 1, Leaflets A8, A9 and E1.

INSTRUMENTS

1. THE ENGINE SPEED INDICATOR

THE Engine Speed Indicator, as its name implies, is used to indicate the rate of revolution of the crankshaft of the engine. It is sometimes called a Revolution Indicator or Tachometer, but it must not be confused

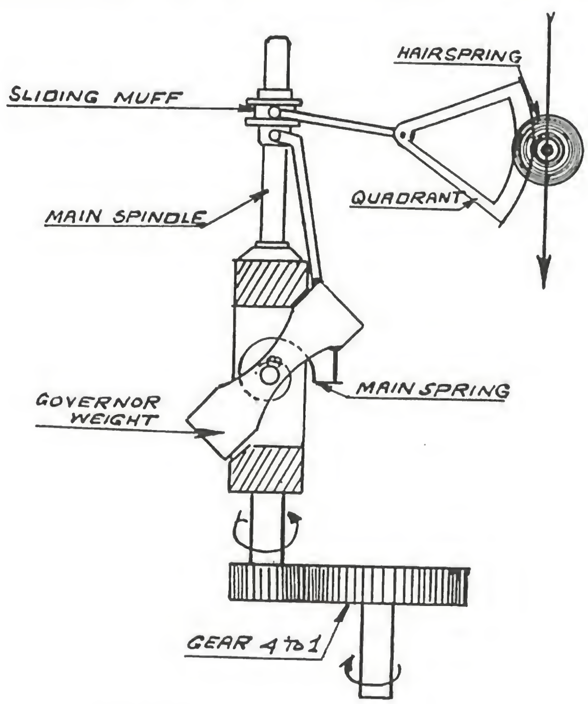


DIAGRAM OF ENGINE SPEED INDICATOR MECHANISM
FIG. 1

with a Revolution Counter, an instrument which counts the actual number of revolutions.

Knowledge of the number of revolutions per minute of the engine crankshaft is of the utmost importance to the pilot. The power developed by an engine depends on the speed and an engine develops the greatest power at a definite number of r.p.m. This is the best working speed and the engine speed indicator gives a definite and rapid indication of any falling-off in speed and, thus, of the power of the engine. Immediately before a flight, the engine is always "run up" on the ground, and the flight is not commenced until the indicator shows that the necessary adjustments have been made and the engine is working efficiently. The r.p.m. obtained when running up will be less than the correct working speed at full throttle

in the air. In flight, the pilot endeavours to keep the engine running at the correct speed and the indicator enables him to do so and to avoid the danger of overstressing by excess of speed.

The type of instrument in most general use is based on the principle of the "centrifugal governor," invented by James Watt, who first applied it to stationary engines.

The main spindle of the instrument is usually driven at engine speed in order to obtain sufficient control from the governor. The flexible drive operating the instrument is usually run at one-quarter engine speed in order to reduce wear and tear. This arrangement necessitates a gearbox (usually 4 : 1 ratio), which is incorporated in the base of the instrument. A pivoted weight carried by the spindle rotates with the latter, and alters its position as the speed varies. As the speed increases this governor weight (shown in Fig. 1) tends to assume a horizontal position due to centrifugal force, causing the sliding muff to move down the spindle. The tail-piece of the quadrant engages in a groove in the muff and its movements are communicated through a pinion to the pointer which will then move clockwise over a graduated scale. The weight is controlled by a spring, so that it returns towards its initial position as the speed falls to zero. It will be seen that the instrument is designed so that the movement of the pointer is always in the same direction, whether the spindle is rotated clockwise or anti-clockwise. The direction of rotation is determined by looking along the driving shaft *towards* the instrument.

Different makers adopt different methods of arrangement of the governor and actuating mechanism. In the "**North**" type originally made by North & Sons of Watford, the weight takes the form of a cylinder bored out centrally at right angles to its axis. The cylinder is pivoted to a frame fixed to and rotating with the main spindle, thus acting as a flywheel and damping out movements due to variations in speed caused by whip in the flexible shaft. (Whip is caused by incorrect fitting or insufficient lubrication.) A coil spring is fitted to the transverse spindle which carries the weight in order to restrain the movements of the weight, which are transmitted to the spring by a steel pin nipped between recesses formed in the underside of the weight and the flattened end of the coil spring. The weight is connected to a sliding collar in which the tail arm of the toothed quadrant engages. Thus the quadrant is rotated and turns the pinion on the pointer spindle. A hairspring attached to the pointer spindle reduces the effect of backlash.

In the "**Elliott**" type of mechanical engine speed indicator, two weights are carried on a rectangular frame, which is pivoted to the main spindle at its centre. The movements of the weights are restrained by an involute coil spring fitted between the side plates of the framework. The lower weight is linked to a collar which slides on the main spindle, and is provided with a groove in which the pin of a crank, carrying at its other end a toothed quadrant, engages. The pinion on the pointer spindle engages the teeth of the quadrant. The action is as follows: As the speed increases, the weight tends to move outwards from the centre spindle, drawing the collar carrying the crankpin up the spindle. The crank is thus rotated, and its movements are magnified by the quadrant and pinion mechanism used to rotate the pointer. A hairspring is attached to take up the backlash in the gearing. Near the top of the main spindle is fitted a light drum, marked on the outer side with a zig-zag line, which can be observed through an aperture in the dial. By this means the observer can ascertain whether or not the engine is running when the speed is so low that no indication is given by the pointer.

The Mark VI instrument is provided with a movable lubber mark, carried on a split ring in the upper portion of the flange which holds the

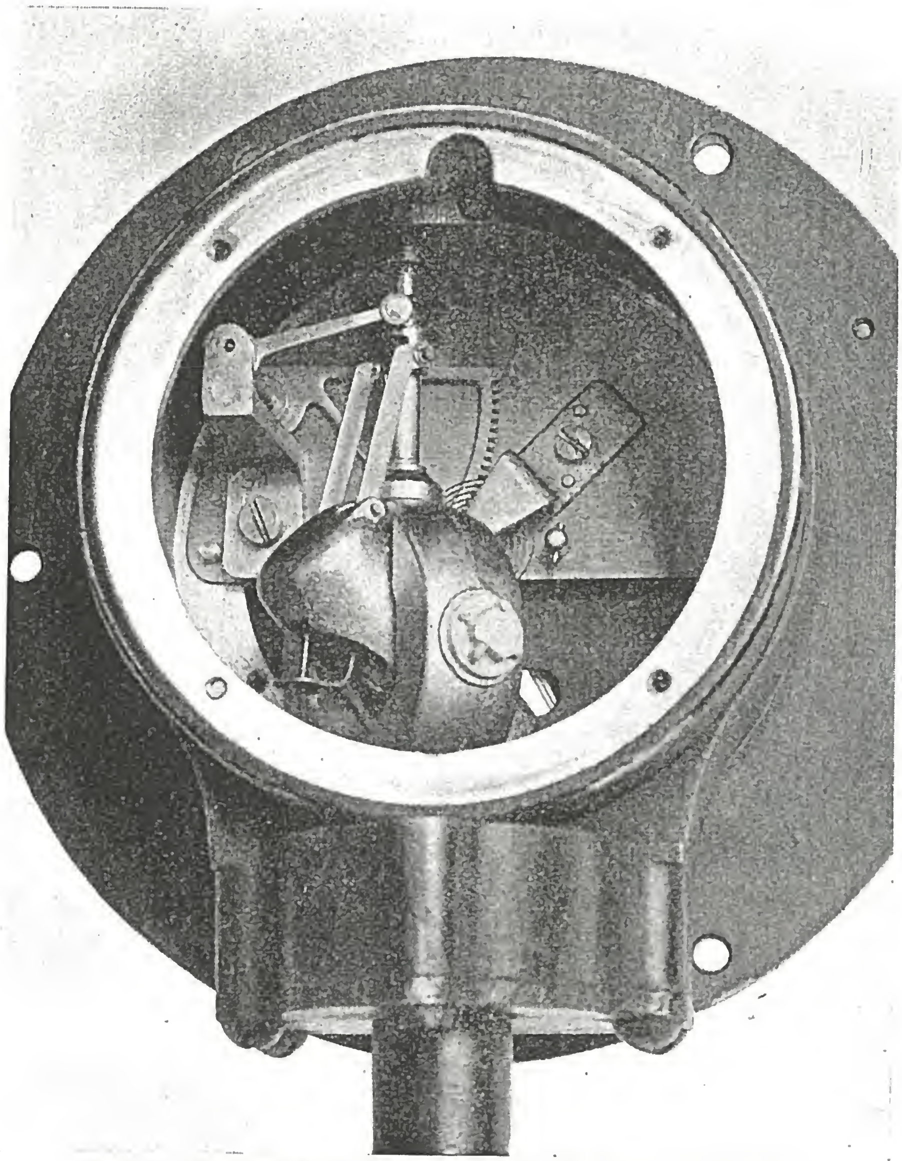


FIG. 2. MECHANISM OF "NORTH" ENGINE SPEED INDICATOR

glass front in position. This split ring can be turned so as to adjust the lubber mark to the normal speed of the engine.

Recent types of engine speed indicators (e.g. Mark IX) are fitted with screwed plugs at the top and bottom of the case, giving access to the grease ducts to the bearings. These are packed with grease during manufacture, and should be refilled occasionally.

The Drive

The indicator is connected to the engine by means of a flexible shaft

(which generally runs at one-quarter engine speed) contained in a flexible casing. The standard drives are Mark IVa (up to 12 ft. in length) and Mark VI (over 12 ft.). Other forms of drive are permitted provided they pass the tests. The cable is stranded, consisting of an inner core surrounded by stranded wire. Four right-hand and four left-hand strands are laid on alternately, until the diameter of the completed shaft is 4 mm. in the Mark IVa or 6 mm. in the Mark VI drive. The ends of the drive are soldered into standard connectors, terminating in short, squared ends, which engage in squared holes in the indicator shaft and the engine connexion respectively. The inner cable runs in a brass flexible outer casing jointed with asbestos to prevent leakage of the lubricating grease. The flexible drive is coupled up to the indicator and gearbox by ordinary coupling nuts. Thirty feet is the greatest length practicable for a flexible drive. If longer, strains are set up resulting in jerky readings as the result of friction.

Flexible drives used with engine speed indicators are provided with vent holes to prevent derangement of the indicator due to the entry of oil and grease forced along the flexible drive by engine pressure. Two vent holes $\frac{1}{8}$ in. in diameter are drilled opposite to one another, in the casing collar at the engine end of the flexible casing $\frac{3}{4}$ in. from the open end.

The Gearbox

When the indicator driving shaft of the engine does not run at one-quarter of the crankshaft speed a gearbox is used to bring the flexible shaft to that speed. Two types of gearbox are employed: (*a*) the "straight through" type connected by a flexible coupling to the driving shaft, and (*b*) the "right angle" type, used when the drive must be fitted at right angles to the engine shaft owing to spacing difficulties. The use of a flexible coupling ensures evenness of running and prevents undue wear due to any lack of alignment.

When two indicators are provided for the same engine, a dual drive gearbox is fitted. Two outgoing flexible shafts to the two indicators are driven from one ingoing flexible shaft from the engine. In the gearbox are three parallel spindles each carrying a spur wheel. The central spindle is driven by the engine. Two lugs are provided on the casing for attachment to the aircraft. Mark VI (6 mm.) drives should be used throughout.

Special grease (free from acid or alkali), which does not run at a temperature of $+ 50°$ C., or become too stiff at $-20°$ C., should be used for gearboxes.

Installation

Before installation the flexible drive should be carefully examined. It may be withdrawn from the casing by removing one of the split washers at the end of the casing. When this washer is replaced, care must be taken not to leave it twisted. The shaft must be thoroughly greased with a suitable lubricant. The squared ends should be an easy fit in the corresponding squared holes in the gearbox and the indicator, and should be kept well greased. On no account must the small collar on the squared end bind when the nut is tightened, or jerky readings and possibly breakage of the shaft will result.

It is important that the drive should be installed with as few bends as possible, and in no case should the drive be bent to a radius of less than 9 in., otherwise undue wear will be caused. A test for freedom of the shaft should not be omitted. When one end is coupled up to the indicator it should be possible to turn the shaft from the engine end by

the use of the fingers alone, except perhaps in the case of very long drives. The length of the casing should then be checked and adjusted as necessary to suit the length of the shaft. The adjustment can be made by twisting the casing slightly so that the free end of the shaft does not press too hardly on its washer, nor stand proud more than $\frac{1}{4}$ in. when held close up to the connexion.

Unless absolutely necessary, it is never advisable to attempt to shorten the inner shaft. But if it is essential the following standard method should be employed—

1. Unsolder one steel squared end, heating carefully so as not to impair the shaft by overheating.

2. Cut the shaft to the required length. Before cutting, the shaft

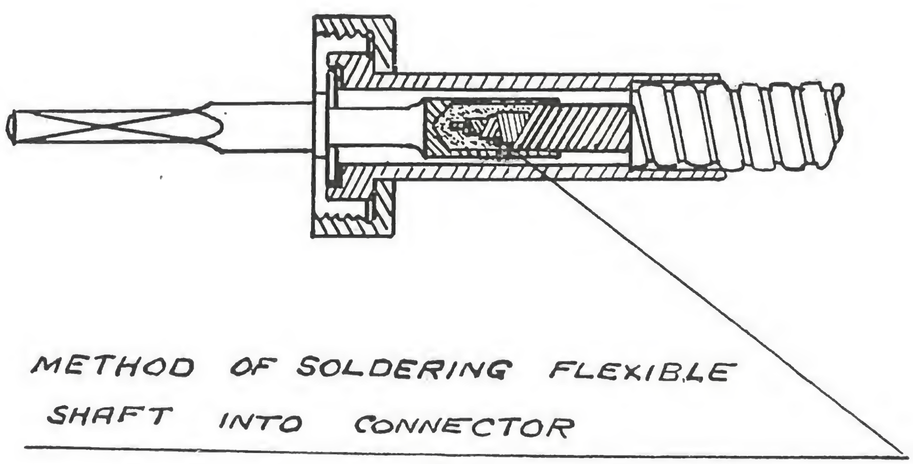


FIG. 3

should be soldered at the point where the cut is to be made, so that the external windings are held. Strip off the layers of wire at the butt in turn by unwinding the outside layer a small amount, and the next layers by decreasing amounts, and fix with solder in each case to prevent unwinding. (Fig. 3.)

3. Clean the bared ends well with emery cloth and petrol, prepare with Fluxite or other non-corrosive flux, and tin thoroughly.

4. Clean out the squared end socket and treat with Fluxite.

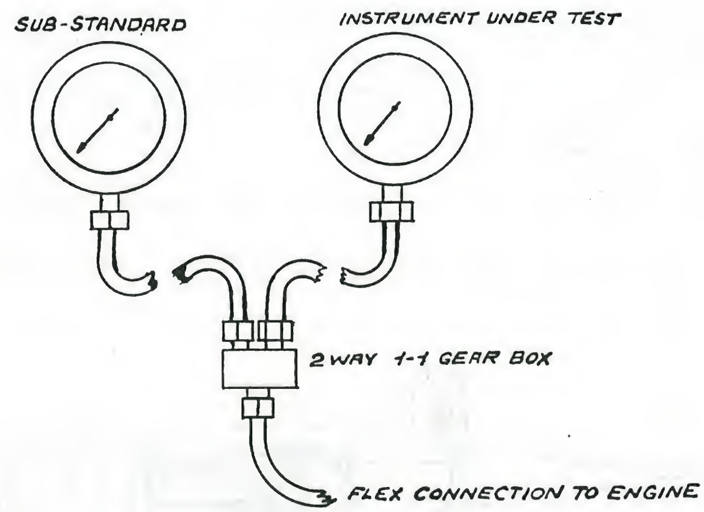
5. Heat the socket in the flame of a bunsen burner and fill it with solder.

6. When the socket hole and the end of the shaft are well tinned, push the shaft with a twisting motion into the molten solder in the socket.

On no account must the bunsen flame be allowed to play directly on the shaft, as this may reduce its strength to a dangerous degree.

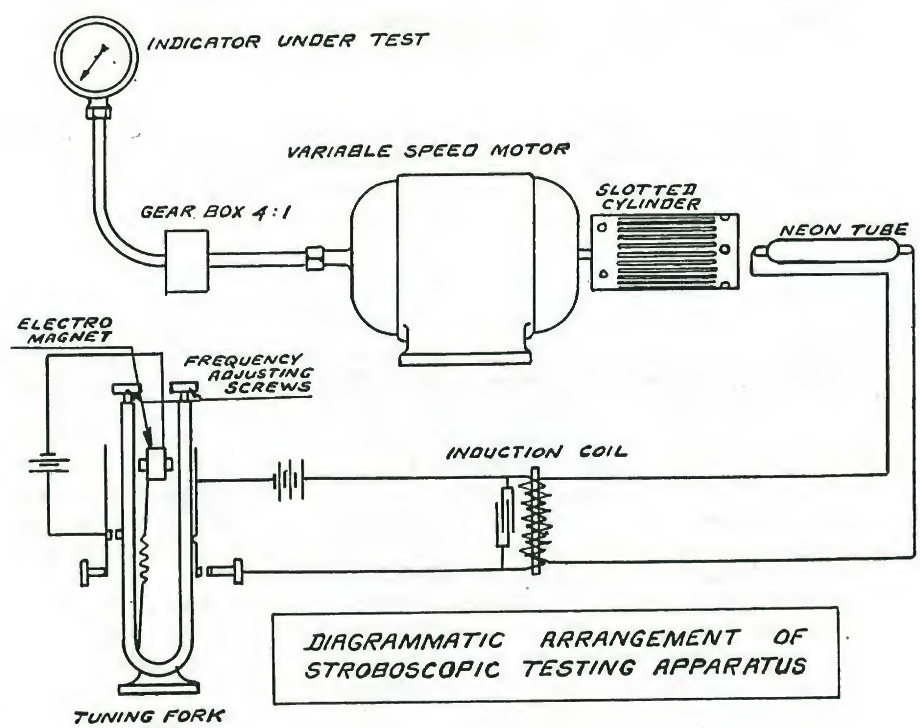
The casing must be securely clipped in position, especially at the bends, so that no unduly long length remains unsupported. If this is not effectively carried out, movement of the part unsupported will almost certainly set up oscillations of the pointer of the indicator.

Unless a special lubricating device is fitted, no lubrication of the indicator should be attempted. The original supply of lubricant to the muff, gears, and main bearings should be sufficient for 300 hours' running. The main spindle should be highly polished and dry. If the accuracy of the readings is suspected, the instrument should be uncoupled and another substituted.



CHECK TEST ON ENGINE SPEED INDICATORS

FIG. 4



DIAGRAMMATIC ARRANGEMENT OF STROBOSCOPIC TESTING APPARATUS

FIG. 5

If these precautions are observed in installation very little trouble should be experienced, and undue wear will be avoided, resulting in longer life.

Check Tests

A simple check apparatus can easily be fitted up if a two-way gearbox, an indicator known to be reliable (or a sub-standard), and a flexible shaft run by a variable-speed motor are available. The two indicators are coupled up to the two-way gearbox, which is run by the flexible shaft driven by the motor. The speed of the motor is varied gradually, and the reading of the instrument under test compared with that of the new indicator. Alternatively the gearbox may be driven direct by the drive from the engine of the aircraft.

Check of Engine Speed

A check on the accuracy of the engine speed indicated may be carried out by a portable rotoscope, such as the "**Ashdown**" rotoscope (see Appendix IX), when the aircraft is stationary on the ground and the engine running. A clearly visible mark on the propeller boss is observed through the rotoscope, which is adjusted until the mark on the boss appears stationary. The observer then signals an assistant in the cockpit, who notes the reading of the indicator. The error of the indicator is the difference between the observed indicator reading and the actual revolutions per minute as indicated by the rotoscope. By this method an accuracy to 1 per cent should be reached. The necessary correction must, of course, be made in the case of a geared propeller.

Accurate Testing

Accurate checks of engine speed indicators are most conveniently made in a laboratory or test house which is suitably equipped with a stroboscopic apparatus. One form of apparatus may be briefly described.

A variable-speed electric motor running off a constant voltage supply is used to rotate a metal cylinder mounted on its main shaft. Thirty slots, equally spaced, are cut longitudinally in the cylinder, the interior of which is illuminated by a neon tube in the secondary of an induction coil circuit, the primary current of which is interrupted 50 times per second by means of an electrically-driven tuning fork. Thus the neon tube flashes 3,000 times per minute. The duration of the flash is only a few millionths of a second, but owing to persistence of vision the neon tube appears to be continuously illuminated when the motor is not running. Suppose the speed of the motor is gradually raised by means of the coarse and fine resistances provided until it reaches 100 r.p.m. At this speed, light from one flash of the neon tube may pass through one of the slots and enter the eye of the observer. After an interval of $\frac{1}{3000}$ minute the next flash takes place at the moment when the next slot is in line with the observer's eye. Successive flashes take place at instants when successive slots are in the line of sight, and the slots will then appear to be stationary. If the speed of the motor is raised to 200 r.p.m. the same effect is observed, a flash taking place at the instant when every alternate slot is in line with the eye. Thus the stationary effect occurs at every multiple of 100 r.p.m.

If the speed of the slotted cylinder is a little less than an exact multiple of 100 r.p.m., the slots will appear to rotate slowly in the opposite direction to that of the motor. If the speed is slightly higher, the slots will appear to rotate slowly in the same direction as that of the motor. One apparent revolution per minute corresponds to a difference of speed of 1 r.p.m.

The instrument under test is run by the same motor through a gear-box. The speed of the motor can be brought to successive multiples of 100 r.p.m. by observing the stationary positions of the illuminated slots in turn, and the errors of the indicator at each point noted.

Up and down readings are taken, and the direction of the motor can be reversed to allow of such readings being taken for both clockwise and anti-clockwise rotations of the spindle.

The accuracy of the method clearly depends on the accuracy of the tuning fork, which must be checked periodically.

Tel Engine Revolution Indicator and Recorder

The Tel Indicator and Recorder is largely used on British commercial aircraft. It not only records the engine speed and the total revolutions but provides a chart record of the variations of speed during flight along a time scale, governed by an eight-day clock incorporated in the instrument. The instrument is usually fixed in an exposed position, and great care should therefore be taken in installing and clipping the flexible drive to prevent oscillations of the pointer. Recent forms of the instrument incorporate agate pointed styles working on semi-transparent varnished paper which avoids paper fluff. No attempt should be made to repair this instrument if the readings appear to be untrustworthy, but the whole instrument should be returned to the makers for overhaul. Further details of the mechanism are given in Appendix VIII.

FIG. 6. "HASLER" TEL ENGINE SPEED RECORDER

FIG. 7. "RECORD" ELECTRICAL ENGINE SPEED INDICATOR (EDGEWISE TYPE FOR TRIPLE-ENGINE MACHINE)

Electrical Types of Engine Speed Indicators

There are several types of electrical engine speed indicators in use, and they are particularly valuable when it is desired to use an indicator at

a distance from the engine greater than 30 ft., the maximum distance practicable for a flexible shaft. The connexion between the instrument and the generator is made by flexible electric cable, which may be of considerable length.

The principle of construction employed in more than one type is that of an electric generator driven from the engine, either by suitable gearing or a short flexible shaft. The indicator is essentially a voltmeter calibrated to read directly in revolutions per minute and placed in circuit with the generator. As the volts produced by the generator increase with

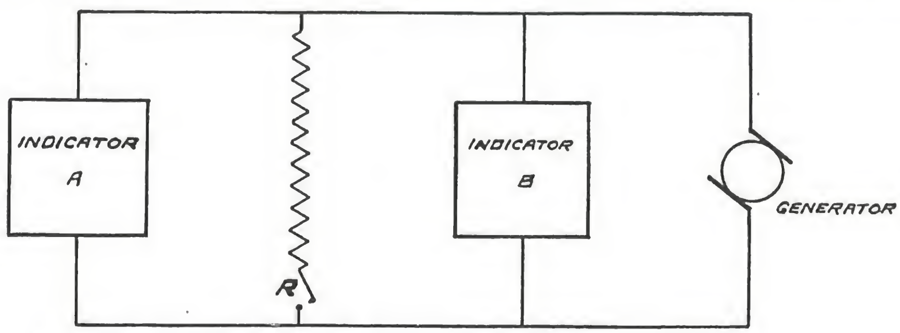


FIG. 8. DIAGRAM OF CONNEXIONS FOR TWO ELECTRIC REVOLUTION INDICATORS WORKING IN CONJUNCTION WITH A SINGLE GENERATOR

If the indicator *B* is not in use, the switch *R* must be closed to include the substitutional resistance in the circuit. This resistance is usually incorporated in the generator

the speed, the indications of the pointer on the dial can be made to serve as a measure of the speed.

In the past, electrical indicators have presented special difficulties to the designer owing to temperature errors, and the gradual loss of magnetism

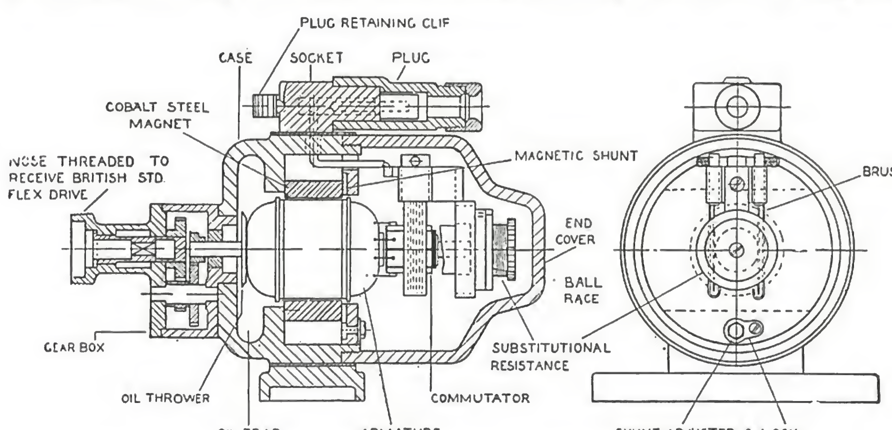


FIG. 9. DIAGRAM OF GENERATOR FOR "RECORD" ENGINE SPEED INDICATOR

in permanent magnets, if these are used in their construction. They are more difficult to construct to the same degree of accuracy or robustness as the mechanical types, and require periodic attention to maintain them in an efficient condition. They should be periodically checked for accuracy of calibration.

The **Record** Electrical Company have developed an electrical indicator used in conjunction with a generator which incorporates a cobalt-steel magnet. In the field of this magnet revolves a multi-pole armature which is standardized to give 30 volts at 3,000 r.p.m. At lower speeds, the voltage output is directly proportional to the speed. Four-to-one gear-wheels are fitted for use with flexible shafts run at one-quarter engine speed. It is advisable, after the generator has been run for about 500 hours, to remove the brushes (conveniently arranged for the purpose) and clean the commutator. Worn brushes should be replaced. No lubrication should be used on the commutator. The bearings and gearbox are packed with special grease to withstand extremes of temperature. The "**Cirscale**" type is the ordinary dial pattern. The "**Edgewise**" type indicator has been designed for compactness, and for easily comparing the speeds of the engines on multi-engine aircraft. It is constructed on the unit principle, each voltmeter being a complete and separate unit with a pointer moving over the edge of the dial which is set edgewise to the observer. Two or more of these indicators are fixed side by side on a base for use with two or more engines. Special plugs and sockets are provided for coupling up to the generators. Any length of flexible cable up to 50 yards may be used without affecting the accuracy of the calibration. The flexible drive used is the same as that for mechanical types, except that the squared ends are ½ in. instead of 1 in. long. Permissible errors are $\pm$ 10 r.p.m. on the generator and $\pm$ 10 r.p.m. on the indicator.

The "**Weston**" Type 544, E, generator is designed for direct mounting on the engine. It is specially intended for use on engines equipped with standard connexions, and can be screwed and locked in place on the coupling without the need of additional supporting brackets or flexible drive shaft. The indicator is a "Weston" voltmeter of the permanent magnet moving coil type with a scale calibrated in revolutions per minute. The makers guarantee an accuracy within 2 per cent for this equipment.

Types

For civil aircraft the following types are permitted—

Mark	Range	Diameter of Dial	Type
	r.p.m.	in.	
Va	600–2,600	4	Mechanical
Vb	600–2,800	4	Mechanical
Vc	800–3,000	4	Mechanical
VI	600–2,600	6	Mechanical
IXa	1,200–3,400	3⅛	Mechanical
IXb	600–2,600	3⅛	Mechanical
IXd	1,600–4,000	3⅛	Mechanical
IXf	2,000–5,000	3⅛	Mechanical
Elliott Type XVI	500–4,000	2¼	Mechanical
Pioneer 347	500–2,500	3	Mechanical
Tel.	0–2,500	—	Mechanical
Weston 544	0–3,000	—	Electrical
Record Edgewise*	0–3,200	—	Electrical
Record Circscale	0–3,000	4	Electrical

* Other types, both twin and triple pointer instruments, of different ranges up to 3,300 r.p.m. are in use.

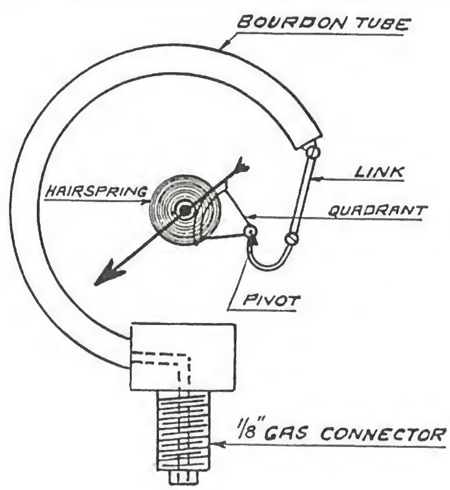
In addition, any instrument may be used which complies with Civil Instrument Specification No. 4A (see page 125), which lays down the minimum requirements for Engine Speed Indicators.

2. PRESSURE GAUGES

The pressure gauges normally used in aircraft are: (*a*) the Fuel or Air Pressure Gauge—a low range gauge to indicate the pressure of the fuel supply system or of the air pressure system in pressure feed petrol tanks, and (*b*) the Oil Pressure Gauge, used to indicate the pressure in the engine lubricating system.

The Bourdon Tube

The principle of the Bourdon tube is almost universally used in pressure gauges of the above types. The Bourdon tube takes its name from Bourdon, a Parisian instrument maker, who patented the device in 1850. It consists essentially of a metal tube of oval cross-section, bent or swaged longitudinally into nearly circular form. One end of the tube is closed and free to move, while the other is rigidly fixed and connected to a suitable union for attachment to the fuel or oil pressure pipe lines. Any pressure inside the Bourdon tube, above that of the atmosphere, tends to make the oval section circular and therefore straightens the tube. The free closed end consequently moves through a small distance proportional to the pressure applied. This movement is transmitted by a link and toothed quadrant engaging with a pinion on the spindle of the pointer. The dimensions of the link, the diameter and number of the teeth of the pinion are chosen to give a suitable magnification. A hair-spring is fitted to the pointer spindle to take up backlash, and a stop limits the movement of the Bourdon tube in case of excessive pressure. Another stop is also fitted to prevent the quadrant from accidentally coming out of engagement with the pinion.



PRESSURE GAUGE MECHANISM

FIG. 10A

Fuel or Air Pressure Gauges

The following are types of fuel gauges approved for civil aircraft—

	Range lb./sq. in.	Permissible Error	Maximum Load	Diameter in.
Mark VI . . .	0–5	0·3	15	2
Mark VIa . . .	0–10	0·3	30	2
Pioneer . . .	0–10	—	—	2

Marks VI and VIa gauges are fitted with a lubber mark carried on a

split ring, so as to grip the inside of the instrument case sufficiently tightly to prevent accidental displacement or movement through vibration. This lubber mark should be set to indicate maximum permissible pressure. In general the pressures for fuel purposes range from about 18 in. of petrol, or ½ lb. per sq. in., to 14 ft. of petrol, or approximately 4½ lb. per sq. in., but gauges should be constructed to withstand an overload pressure of at least double the scale range.

Fuel Pressure Gauge (Negretti & Zambra)

A neat type of Fuel Pressure Gauge (of the "Edgewise" type) made by Messrs. Negretti & Zambra is shown in Fig. 10B. The pointer moves over a vertical scale and the space occupied on the instrument panel is only 1¼ in. × 2½ in. The instrument is a transmitting type obviating direct connexion with the fuel supply with the possible danger due to breakage of the connecting pipe or failure of the gauge mechanism. The movement consists of a small corrugated capsule of special design which operates the pointer through a series of spring-pivoted levers. The capsule is connected by tubing (of small bore and small external diameter) to a second "weak" capsule housed in a casing so that the pressure in the fuel system is exerted on it. The indicator—capillary—capsule system is gas-filled and hermetically sealed. The pressure sustained by the "case-capsule" is transmitted to the "indicator-capsule" by the contained gas. The design is such that the variations of external pressure due to altitude do not cause appreciable errors. The capillary is protected by a waterproofed braided cotton covering.

Oil Pressure Gauges

Approved types of oil pressure gauges are—

	Range lb./sq. in.	Permissible Error lb./sq. in.	Maximum Load lb./sq. in.	Diameter in.
Mark Va	0–25	0·8	100	2
Mark Vc	0–100	3·3	200	2
Mark VII	0–25	1·0	100	4
Mark VIIa	0–150	5·0	300	4
Mark VIIIa	0–25	2·0	50	2
Mark VIIIc	0–100	3·0	200	2
Pioneer 505	0–120	—	—	2¼
[1]Negretti & Zambra IXc	0–100	2·0	200	2½
[1]Negretti & Zambra IXd	0–200	2·0	—	—

In addition, any instrument may be used which complies with Civil Instrument Specification No. 5 (see page 126), which lays down the minimum requirements for Pressure Gauges for Oil and Fuel systems.

In the case of all oil pressure gauges, provision is made for overload pressures up to 100 per cent of the scale range. This is necessary owing to the possibility of such pressures being experienced when starting an engine from cold. If the gauge fails, lubrication may be curtailed, with a consequent risk of seizure of the engine. This risk is obviated by the use of the transmitting type of gauge.

[1] Transmitting types.

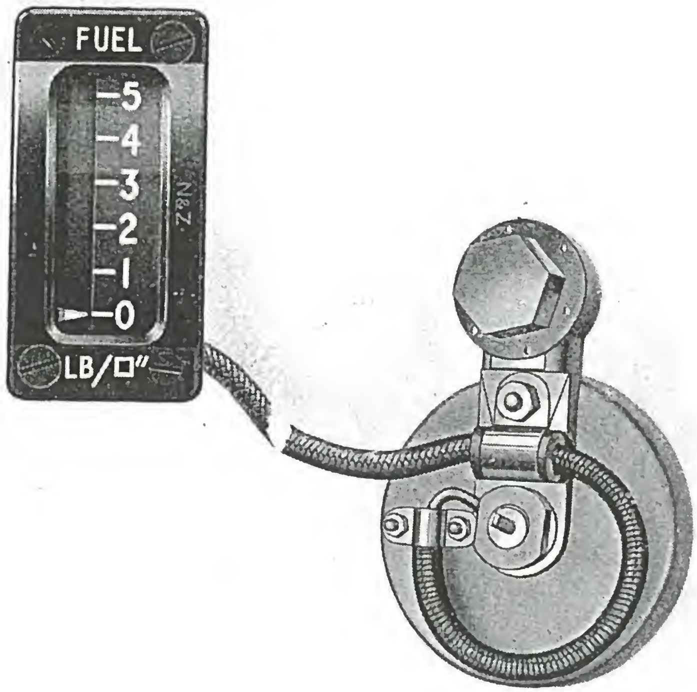


FIG. 10B. FUEL PRESSURE GAUGE
(Negretti and Zambra)

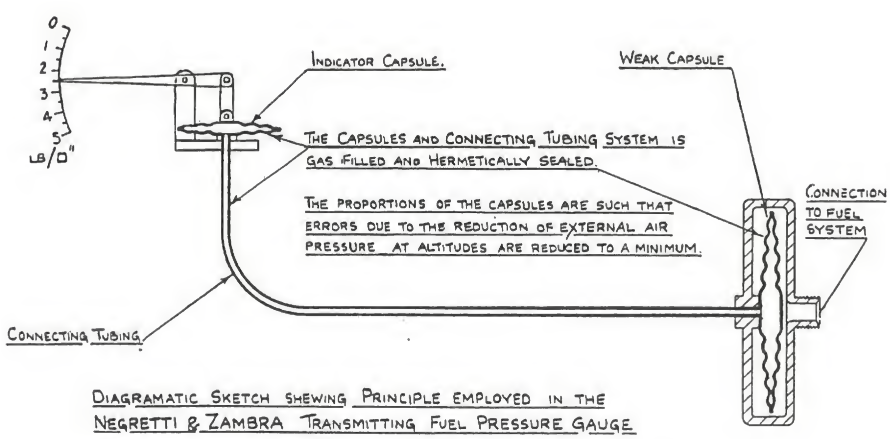


FIG. 10C MECHANISM OF FUEL PRESSURE GAUGE

Transmitting Pressure Gauge

The Transmitting Pressure Gauge consists of a flexible diaphragm which is connected by means of a fine bore capillary tube to the Bourdon tube of the gauge. The whole system is filled with a suitable non-freezing liquid, such as paraffin or ethyl-alcohol, which acts as a transmitting

FIG. 11. OIL PRESSURE GAUGE (TRANSMITTING TYPE)
(Negretti and Zambra)

medium to transmit the pressures applied at the diaphragm to the Bourdon tube. The diaphragm is mounted in a suitable case which itself is connected to the oil pump body or other part of the oil supply system remote from the dashboard, and the oil itself is, therefore, entirely isolated from the distant indicator. (See Fig. 12. The oil pressure is applied at *A*.)

The capillary tubing is constructed of well annealed material, such as a copper-nickel alloy (80 per cent Cu.) of external diameter approximately

0·075 in. and bore 0·02 in. It is protected by servings of cotton in two layers wound in alternate directions treated with an approved black wax compound and by a braided outer covering with a further final treatment with the compound. The tubing has to pass the specified bend and fatigue tests.

This type of gauge is chiefly used when comparatively long oil pipe-lines would be necessary, as in the case of multi-engine aircraft where the engines are some distance from the instrument panel. Direct communication between the gauge and the lubricating system is not always advantageous owing to (*a*) the cooling effect of the long pipe-line in which the

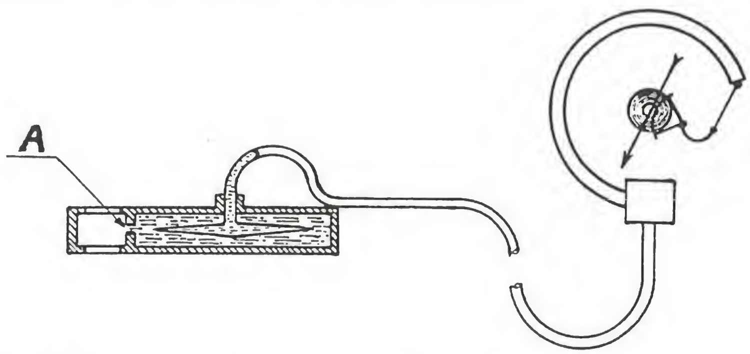


Fig. 12. Diagram of Oil Pressure Gauge (Transmitting Type)

oil might tend to congeal, and (*b*) the risk of fracture in the pipe-line, with consequent serious leakage of oil.

Installation

When connecting the pipe-line to the direct action type of gauge, care must be taken to ensure that a leather washer of the correct thickness is fitted over the spigot on the gauge connexion, and that there is no risk of this blocking the orifice leading to the Bourdon tube. Before coupling up, the pipe-line should be carefully bent to the gauge connexion in order to avoid strain on the soldered joint between the pipe and the nipple. Before connexion is finally made, the pipe-line should be carefully supported by clips at short intervals along its entire length. Sharp bends should be avoided.

A leak in the Bourdon tube is the most common cause of failure of a gauge. This defect, however, is much less common than formerly owing to the better quality of tubes now made. If the Bourdon tube does leak, the defect will be evident, as the instrument case becomes filled with oil.

If the accuracy of calibration is suspected, the pressure should be released and the gauge carefully watched as the pointer returns to zero. Generally there is no stop at the zero, so the pointer should "float" at this point. If there is no error at zero, large errors of calibration are extremely unlikely.

When installing the transmitting type of oil pressure gauge, the indicator is fitted to the instrument panel, and the transmitting diaphragm box to the oil pump body or other convenient part of the oil supply system.

The capillary should not be uncoiled by pulling it straight out. It should be unwound, care being taken to avoid twisting, and on no account should it be bent sharply round corners.

The diaphragm box is connected to the oil pump casing by means of

a special hollow stud, making sure that the two washers are placed correctly, one on each side of the diaphragm box. The nut should be secured by threading a length of copper wire through the holes in its flange. Copper piping should not be interposed between the diaphragm box and the main oil supply. When the gauge or diaphragm box is subject to engine vibration the capillary should be looped at the point where it leaves the flared end on the gauge or diaphragm box, in such a way that it can be secured by a special clip to the flared end, forming a coil about $1\frac{1}{2}$ in. in diameter. (See Fig. 23.) The capillary should be supported by clips to avoid excessive vibration either from the engine or from the air flow. Special care should be exercised to avoid strain by tension or twisting. It should be clear that the capillary must on no account be broken or disconnected from either the indicator or the diaphragm box or the transmitting liquid will be lost and the instrument rendered useless.

Check Tests

Simple check test apparatus for fuel pressure gauges is shown in Fig. 13. In testing, the level of the water in the U-tube is adjusted to the zero mark on the scale and the tap *A* is then closed. The regulating tap *B* is closed and air is pumped into the air reservoir by means of the pump. By opening the regulating tap *B* cautiously, the pressure can be adjusted so that the pointer of the gauge is brought to any desired mark. The error, if any, is then read off on the U-tube scale, which is calibrated directly in lb. per sq. in. The pressure can be reduced to atmospheric by opening the tap *C*.

Oil pressure gauges may be checked by the simple apparatus shown in Fig. 14. Before the gauge is connected up, the system must be carefully filled with oil by screwing home the plunger of the pump and gradually withdrawing it as oil is introduced into the arms of the tube by means of a special funnel. The gauges under test are then mounted in position and secured by screwing up the nipples. Pressure is applied by means of the screw, bringing the pointer of the standard gauge to different scale marks in turn. The errors of the gauge under test are then read off directly on the dial.

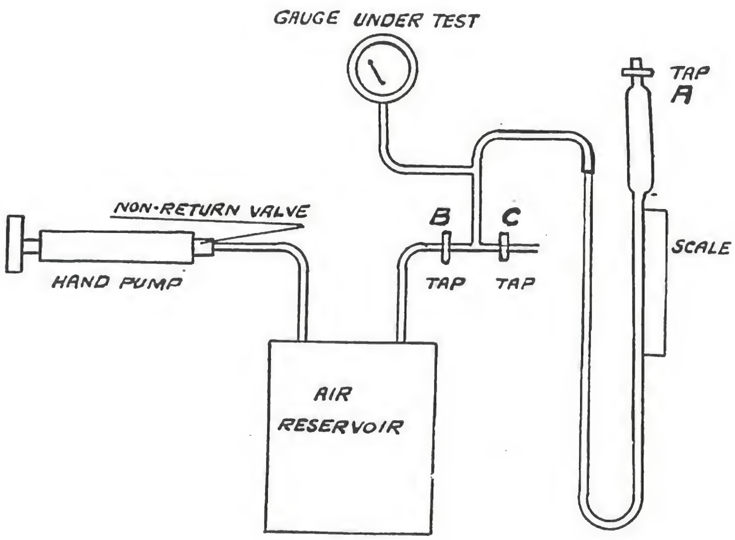
It will be sufficient to take a check at zero, and at one other point of the scale—say about the middle of the scale—in order to dispel any doubt as to the possibility of large errors.

The liquid used in transmitting types of gauge must be such that its vapour pressure at 90° C. is not so high as to cause the instrument to act as a thermometer as well as a pressure gauge. In order to verify this, the indicator may be mounted on a bracket inside an altimeter test chamber so that the dial is visible through a window in front. The capillary passes out through a special split cone gland forming an airtight joint. The capsule is heated in an oil bath to 90° C. and the pressure in the chamber brought to the equivalent of say 40,000 ft. It will be evident immediately if the instrument is acting as a thermometer.

Dead Weight Tests

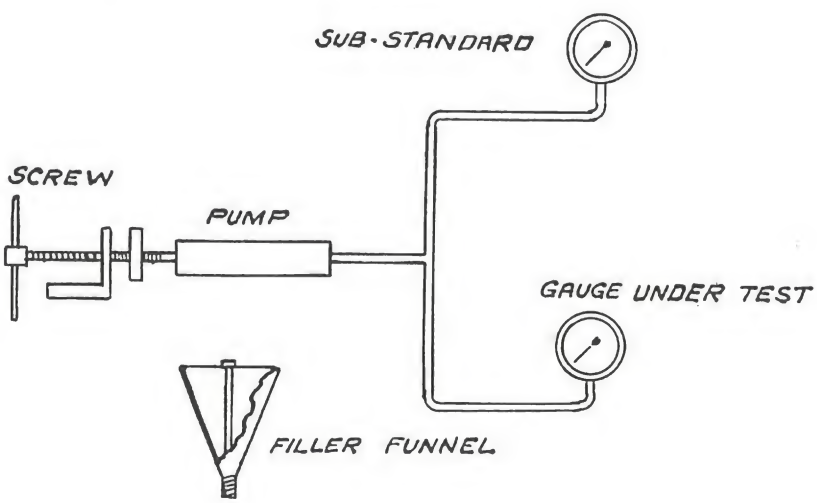
Full and accurate tests of both ordinary and sub-standard gauges can only be carried out on a dead-weight tester in which the pressures are applied by means of actual weights to the oil in the apparatus, and at the same time the pressures are transmitted to the gauge under test.

The oil can be displaced or forced by means of a screw ram into a cylinder which carries a connection to take the gauge under test in such a position that its dial is vertical. The axis of the cylinder is vertical,



CHECK TEST ON FUEL PRESSURE GAUGES

FIG. 13



CHECK TEST ON OIL PRESSURE GAUGE

FIG. 14

and an accurately machined and fitted piston fits into the bore. The piston carries a support for a disc on which weights can be placed. The area of cross-section of the cylinder bore is usually a definite fraction—say $\frac{1}{8}$ sq. in. The disc is then loaded with weights, each the same fraction of its marked weight. The total weight handled in carrying out a test is thus reduced, since the weight marked 200 lb. is actually only 25 lb., but acting on an area of $\frac{1}{8}$ sq. in. produces a pressure equal to

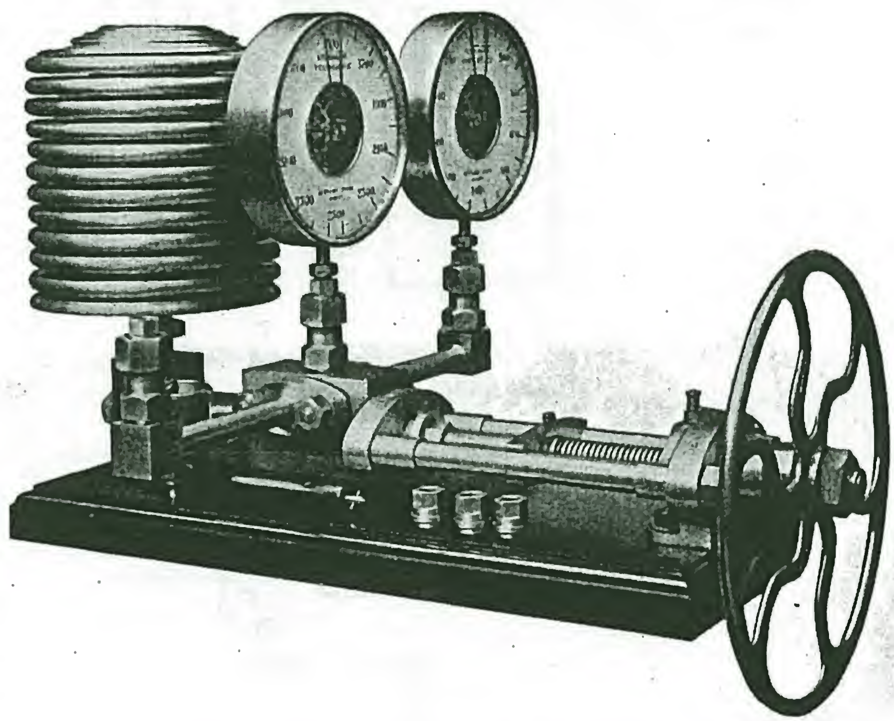


FIG. 15. "DEWRANCE" DEAD-WEIGHT PRESSURE GAUGE TESTER

200 lb. on 1 sq. in. The initial weight of the piston and disc is, of course, taken into consideration when calculating the applied pressure.

The gauge is connected up by a connexion and union nut, a leather washer being used to make a tight joint. The system is then filled with oil as previously described, and the piston placed in position. Weights are added gradually and successive readings taken. An overload test is usually applied to all aircraft gauges, and the maximum load figure given in the table above should be applied. Large alterations in calibration due to the application of the overload pressure must not be permitted, but small differences can be allowed provided the calibration recovers to its normal after twenty-four hours. The total errors must not exceed the figures given in the table above.

In testing a Transmitting Oil Pressure Gauge on a Dead-weight Tester, care must be taken to see that the diaphragm case is at approximately the same level as the top of the oil, or water, column under the dead-weight piston. If there is an appreciably different level, an error will arise, due

FIG. 16. BOOST GAUGE
(*Negretti and Zambra*)

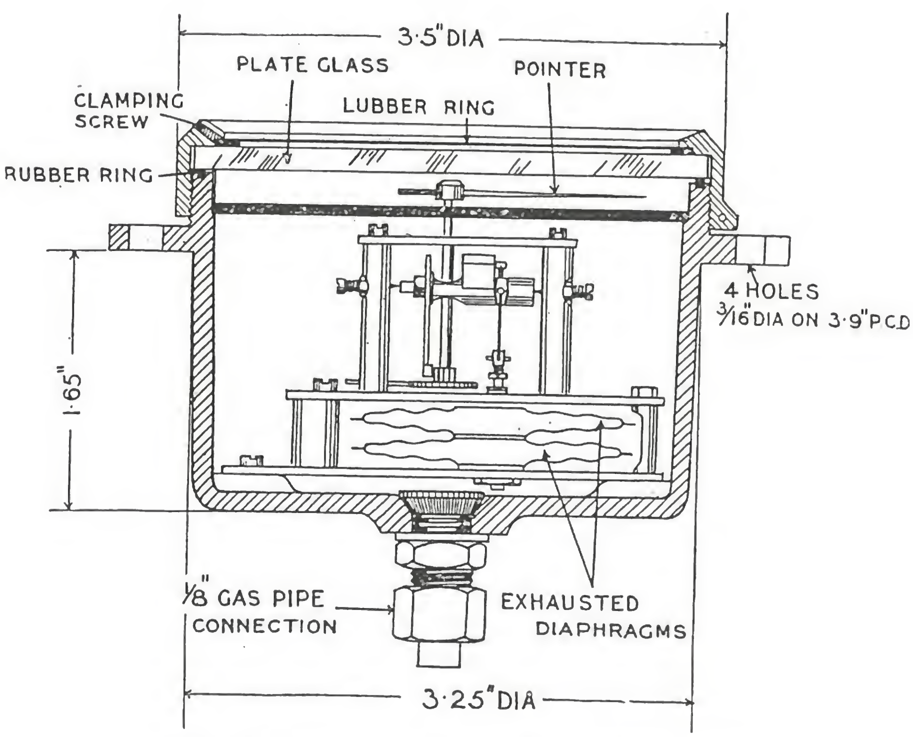


FIG. 17. DIAGRAM OF BOOST GAUGE MECHANISM
(*Negretti and Zambra*)

to the difference in head of the liquids in the gauge system and in the dead-weight tester.

The Boost Gauge

A boost gauge is used on aircraft primarily to indicate the pressure in the induction pipe of supercharged internal combustion engines relative to the atmospheric pressure at sea-level.

The principle of construction is similar to that of the altimeter (Section 7), except that the case is airtight and provision is made for connecting the interior of the case to the induction pipe of the engine. Special sealing washers, made of petrol-resisting material, are used for the bezel, as rubber deteriorates quickly under the action of petrol vapour. The range of the instrument covers from − 6 to + 8 lb. per sq. in. The pointer should indicate zero at standard atmospheric pressure at sea-level. A small sector over the dial can be fixed from outside, and shows the maximum boost permissible for level flight. This is a safety device to prevent overstressing the engine. It is set for the rated boost of the particular engine for which it is supplied, so that the pilot may regulate the degree of supercharge, within safe limits, when operating the throttle. In one type the setting is carried out by removing the slotted cap-nut in the centre of the glass cover, and turning the slotted spindle thus exposed until the sector is in the correct position. The cap-nut is then replaced. In a later type, illustrated in Fig. 16, the sector can be moved to the correct position by loosening a grub screw at the side of the bezel.

The connexion to the induction system is made by a $\frac{1}{8}$-in. gas union threaded through the back of the case from the inside. A lock-nut pulls a circular flange hard up against the casing, forming an airtight joint. A gauze filter fits into the union and should be removed periodically for cleansing. Opportunity should be taken to see the pipe-line is free from cracks and the bore is clear. Occasionally a check of the reading should be made by reference to a standard barometer, the reading of which should correspond with that of the gauge when the engine is cold. The following table gives the calculated readings of the gauge at various barometer readings. The error should not exceed $\frac{1}{8}$ lb. per sq. in. between + 2 and − 2 lb. per sq. in., nor $\frac{1}{4}$ lb. per sq. in. over the remainder of the scale.

Barometer Inches of Mercury	Readings of Boost Gauge lb./sq. in.
28	− 0·95
29	− 0·46
30	+ 0·03
31	+ 0·52
32	+ 1·01

The Mark I A Gauge described above is obsolescent. The Mark II Boost Gauge has a "lubber" ring outside the glass and clamped under the bezel. This takes the form of a red shield with white lettering reading "Maximum Boost Level Flight." The central arrow-head is white. The ring is adjusted in position by slackening the locking-screw and moving the shield until the white arrow-head is brought to a position on the scale corresponding with the rated boost figure for the particular engine with which the gauge is to be used. Thus the second indicating line "Maximum

Permissible Boost" on the earlier type of gauge (implying that the normal boost could be exceeded in certain circumstances) is no longer used. In the Mark II Gauge one indication only—that of "Maximum Boost Level Flight"—is given. The range is—4 to + 4 lb. per square inch.

To obviate the possibility of fuel entering the gauge, a fuel trap is sometimes inserted in the pipe system in a position where it is easily accessible. The pipe from the boost gauge is drained into the trap which is provided with a screwed plug for emptying. After draining the plug must be relocked.

Tests on Boost Gauges

Tests on the minus readings are carried out in the same way as those for altimeters; on the plus readings, as those for fuel pressure gauges. A low-reading standard pressure gauge graduated in tenth-lb. per sq. in. may be used in addition to a mercury column. The pointer of the instrument will not always indicate zero at ground-level, owing to variations in atmospheric pressure. During a test, allowance must be made for any difference from the normal by converting the difference into lb. per sq. in. and applying the necessary correction to the readings of the standard gauge.

The special synthetic rubber sealing washers used for the bezel are apt to shrink in service, and if a leak is suspected the sealing wire should be removed and the bezel screwed up carefully hand tight. The setting of the adjustable lubber mark should then be checked, after which the sealing wire should be replaced and secured by soldering.

In some instruments the synthetic rubber washer is replaced by a dished washer inserted between the glass and the bezel. The action of screwing up the bezel tends to equalize the pressure all round the glass and prevent leakage.

A test for leaks may be carried out as follows: The temperature of the instrument is reduced to -20 °C. and the external pressure to the equivalent of 35,000 ft. I.C.A.N. (i.e. about 7 in. of mercury). A pressure of 7 lb. per sq. in. is then applied to the boost gauge and shut off. The needle should not fall 1 lb. per sq. in. in less than one minute. As the lubber mark is attached to the glass it is necessary to loosen the bezel and rotate the glass to reset the lubber position. A new method of threading the sealing wire through a small lug on the bezel and giving it an extra turn round the case permits a rotation of rather more than a complete turn without breaking the sealing wire.

3. FUEL TANK CONTENTS GAUGE

The regulations require that—

(*a*) Provision must be made in all fuel systems to enable the pilot to ascertain when only thirty minutes supply of fuel at full throttle at international r.p.m. remains. The method employed must not be such as to interfere with the functioning of the power plant or plants.

(*b*) If supplementary tanks are fitted, the pilot must have some indication whether or not the gravity tank is full.

(*c*) When the fuel supply to the engine is by means of a mechanical pump, a pressure gauge and relief valve must be fitted.

The Fuel Tank Contents Gauge is an instrument of some importance, as it is essential that from time to time a pilot should be able to ascertain the amount of petrol remaining in the tank or tanks. Some difficulty has been experienced by instrument makers in designing a gauge that will

give definite and accurate readings and will not be deranged by vibration, liquid swirl, temperature variations or unusually violent movements of the aircraft. Owing to varying dimensions of fuel tanks, it is necessary to calibrate the gauges for the particular machine.

Calibration is carried out as follows—

A temporary disc, graduated in degrees is fitted to the dial of the indicator. The aircraft having been set up in normal flying position, the calibration is carried out by first filling and then emptying the tanks in successive stages, the readings being taken in angular degrees. Measurements should be made in stages of 2 gal. in cases when the tank capacity is less than 90 gal. Above this figure, calibrations should be made in stages of the number of gallons equivalent to approximately 5° on the dial of the instrument. A table is then drawn up giving the calibration in gallons and the equivalent readings in degrees on the scale. In order to avoid confusion, the tank drawing number is marked on the dial of the contents gauge.

The Korect Fuel Contents Gauge

The "Korect" type of gauge measures the difference in pressure between the pressure of the liquid at the bottom of the tank and that of the air above the surface of the liquid. By means of a pump, air is displaced from a tube dipping to the bottom of the tank. The lower end of this dip tube is closed by a small float non-return valve, and the pressure required to open the valve against the head of liquid is read on an indicating gauge, connected with the pump, and reading direct in gallons. The gauge is of the "diaphragm" type, similar to an air-speed indicator, and has an adjustment for setting the zero. The dip tube is enclosed in an anti-surge tube communicating with the tank by holes at the bottom and top. Both tubes are telescopic for adjustment and calibration for use with tanks of varying depth. Special precautions are taken in the design to prevent petrol from entering the pipe-line during flight and while a reading is being taken. A pipe connecting the indicator casing to the top of the tank compensates for pressure difference between the indicator and the tank. Recent forms of the instrument embody a small electric motor and air-pump combined, giving the necessary air pressure required so long as the control switch is in the appropriate position. Provision is made for a continuous stream of air along the compensation pipe-line, as well as along the pressure pipe-line between the tank and the gauge. Thus a balance is secured between the static and hydrostatic pressures, and fluctuations of atmospheric pressures are automatically compensated.

The Televel Tank Contents Gauge

The Televel Tank Contents Gauge is of the float type. It is mechanically operated, and the position of the cork float working on the dip tube is indicated on the gauge through a stiff connecting cable, of which the slack can be wound up on a drum by means of an operating handle on the front of the indicator. When not in use, the cable should be fully wound up by rotating the handle slowly and smoothly as far as it will go in the direction of the arrow marked "UP." In use, the handle is turned so as to move the cable down the interior of the dip tube until the plumb-bob at the end reaches the level of the float. The amount of the fuel remaining in the tank is then indicated on the scale, which is exposed through a small window on the dial. The scale is calibrated usually in multiples of 10 gal.

The Bowden cable must be greased periodically and, if the instrument has not been used for some time, the drum must be wound and unwound occasionally to distribute the grease introduced into the Tecalemit greasers which are placed at intervals along the cable.

Electrical Fuel Level Indicator

An electrical type of fuel level indicator (developed by *Smith's Aircraft Instruments*) comprises a tank attachment fitted with a float carried on an arm which is connected with a vertical spindle. This spindle is attached to a contact arm travelling over a potentiometer, thus applying varying voltages to a deflecting coil at the back of the indicator on the instrument panel. Readings are obtained when the push button on the front cover is operated.

The Fuel Flow Indicator

The Fuel Flow Indicator is an instrument designed for use in the fuel supply system in order to provide a visible indication of the fuel flowing in the pipe-line in which it is inserted. The Dewrance Prismatic Fuel Flow Indicator consists essentially of a chamber with screwed connexions at each end for coupling up. The chamber is provided with a glass window through which the flow is observed. If the flow of fuel ceases, the liquid in the indicator drains back, and the fact that the indicator is empty is more clearly seen by virtue of the fact that the glass window is prismatic.

4. THE RADIATOR THERMOMETER

The thermometer fitted to all water-cooled engines to indicate the temperature of the cooling water is usually of the transmitting type. It is used to warn the pilot against overheating the engine, and the consequent risk of boiling away the limited amount of cooling water in the radiator system. It also gives a warning indication of the overcooling of the engine, and the risk of freezing the water during a long glide from a high altitude. By adjustment of the opening of the radiator shutters, these effects may be partially or wholly compensated.

The bulb is made of brass or copper and is placed in the uptake pipe of the water jacket or at the top of the radiator, so that the indicated temperature is that of the hottest portion of the cooling water. The bulb is connected to the indicator on the instrument panel by means of a copper capillary tube of approximately 1 mm. bore. The indicator is a pressure gauge of the Bourdon type. The Bourdon tube of the gauge, the capillary tube, and a little more than half the bulb are full of liquid. The rest of the bulb, the upper part, contains only the vapour of the liquid. At the bulb end of the capillary tube, the tube is continued down into the bulb so as to dip below the level of the liquid. (See Fig. 18.)

A liquid which is easily volatile, such as ethyl-ether (boiling point 34·6° C.), is used. Its vapour pressure depends solely on the temperature of the liquid, that is, for every temperature there is one definite pressure which is quite independent of the volume of the bulb. One free surface of the liquid must therefore be in the bulb, and this is achieved by the construction shown in Fig. 18. The bulb is normally the hottest part of the instrument and therefore the capillary and the Bourdon tube fill with liquid, and the vapour above the free surface of the liquid exerts a definite pressure on the liquid surface at every temperature. This pressure is transmitted through the liquid in the capillary to the gauge.

As the temperature rises, the pressure will increase and tend to straighten the Bourdon tube, thus causing a movement of the pointer of the indicator over its dial.

The changes of pressure with temperature are shown in the curve (Fig. 19). Below 40° C. the vapour pressures are small, and for this reason the scale of the instrument usually commences at about 50° C.

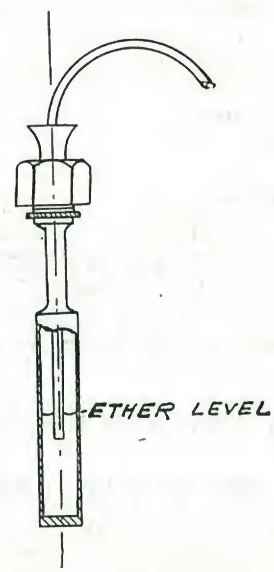


DIAGRAM SHEWING LIQUID LEVEL IN RADIATOR THERMOMETER BULBS

Fig. 18

The dial of the indicator is marked directly in degrees of temperature corresponding to the pressure reached.

Errors Due to Altitude

Such a thermometer is not accurate under all conditions of service. It is liable to errors due to change of altitude as well as the particular conditions of the installation. The instrument really indicates the difference between the vapour pressure in the bulb and the external atmospheric pressure. The latter diminishes as the height of the aircraft increases. Thus, a thermometer graduated correctly at ground-level will read high when the aircraft rises into the air. An instrument which reads 80° C. at ground-level would indicate roughly 85° C. when the aircraft was at an altitude of 20,000 ft. The error due to this cause is on the side of safety, as the thermometer reads high; but it is usual to allow for this. The boiling-point of water varies with the height. It is the boiling temperature of the water which is the dangerous temperature from the pilot's point of view, as it is his aim to prevent the loss of water by boiling away. It is therefore customary to mark the boiling-points in red, on the dial itself, at the various heights; at the same time allowance is made for the effect of altitude referred to above.

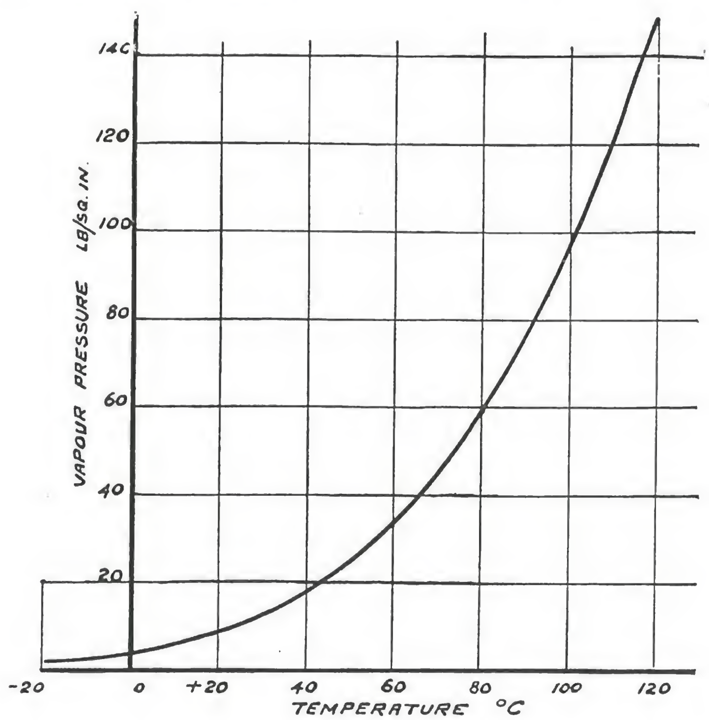
In the diagram (Fig. 20) the apparent boiling temperatures at heights as indicated by the thermometer are given.

Types Approved for Civil Aircraft

The types of radiator thermometer approved for civil aircraft include—

	Range	Dial in.	Permissible Error
Mark Ia . .	50–100° C.	2	− 0 + 3° C.
Mark VI . .	50–100° C.	$2\frac{1}{2}$	− 0 + 2° C.

Both types incorporate a small tube in the gauge to facilitate refilling. It is closed by flattening and soldering the end. The boiling-point temperatures are marked in red on the dial at multiples of 5,000 ft.



CURVE SHOWING VAPOUR PRESSURES OF ETHYL ETHER AT VARIOUS TEMPERATURES

FIG. 19

In addition, any instrument may be used which complies with Civil Instrument Specification No. 7 (see p. 129) which lays down the minimum requirements for Radiator Temperature Thermometers.

Installation

When installing a radiator thermometer, great care must be taken in handling the capillary. It should be cautiously uncoiled so that no unnecessary strain is placed on the soldered end-joints. It should not be bent more than is absolutely necessary. Careless handling may cause leaks to develop, especially in the neighbourhood of the soldered joints.

A leak is quickly detected by the characteristic smell of ether, and, as ether is highly inflammable, any instrument developing a leak should be immediately removed to a safe distance from the aircraft. On no account must the capillary be disconnected or cut in order to adjust its length. If the tube proves to be too long, the excess may be coiled to a diameter of not less than 6 in. Clips with edges free from burrs should be used to

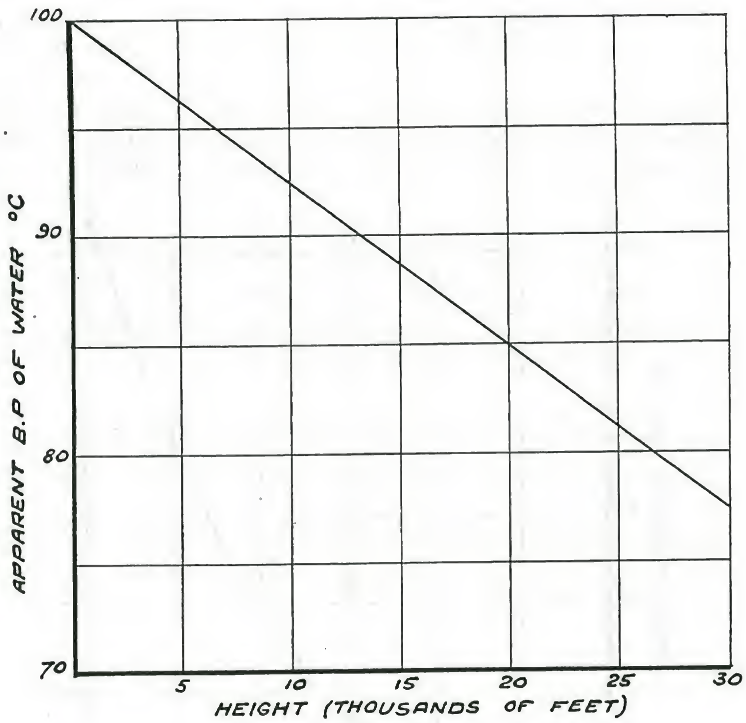


FIG. 20

support the tube at frequent intervals along its length, and every possible precaution taken not to flatten the tube, and to provide against damage due to chafing or vibration. The tube should not be run in the proximity of any part of the engine, where it is liable to get heated, or the accuracy of the readings may be affected.

Check on the Accuracy

If the accuracy of the instrument is suspected, a calibration check should be made in the following way. An ordinary mercury-in-glass thermometer, such as is used in laboratories, is tied to the bulb of the instrument, and the combination used to stir water in a suitable vessel gradually heated by means of a Bunsen burner or other convenient means of heating. The bulb should be immersed to the shoulder and the thermometer to the top of the mercury. Readings should be taken on both scales at intervals as the temperature rises to 98° C. The source of heat is then removed and readings are again taken as the water cools down. The readings are compared and any errors are at once detected. With the indicator and capillary at any temperature between 10° C. and 20° C. and the barometer at 760 mm., the maximum permissible errors are

shown above. The errors due to difference in temperature between indicator and capillary must not exceed 2° C.

THE OIL TEMPERATURE THERMOMETER

The Oil Temperature Thermometer is used to measure the temperature of the lubricating oil in the engine, to avoid overheating, which would impair the lubricating properties of the oil, or overcooling, which would render the oil so viscous that the flow would be impeded. In the case of air-cooled engines the instrument normally provides the only reliable indication of the temperature conditions. For this purpose, the types of thermometer used for indicating temperatures of the cooling water in the radiator are unsuited, as the vapour pressure of ethyl-ether at the lower range of temperature in the neighbourhood of 20° C. is so small that it is difficult to measure with any degree of accuracy. A satisfactory type of instrument, depending on changes in liquid pressure with temperature, has been developed by Messrs. Negretti and Zambra. The bulb, capillary, and Bourdon tube are of steel, and the whole system is completely filled with mercury by exhausting in a high vacuum to remove residual gases, and forcing in mercury at high pressure. The bulb is made of solid drawn steel tube with a flared outlet. into which is welded the steel capillary tube of very fine bore (·006 in. diameter) sheathed with a protective copper or braided tubing. Both the bulb and the copper tube are nickel-plated. The fineness of the bore may be judged from the fact that one mile of capillary would contain about 1¼ cub. in. of mercury. The Bourdon is made of flat steel tubing of small cross-sectional area, coiled in a double spiral, and itself acts as a spring, thus avoiding backlash. When the bulb temperature is increased a certain volume of mercury is forced into the Bourdon tube owing to the expansion of the liquid in the bulb, and the coiled Bourdon tube tends to uncoil and turn the pointer. The effect of the double coil is to ensure concentric motion about the axis of the pointer and minimize friction. Compensation for changes of temperature is effected by fitting a bi-metallic spiral made of brass and invar strip with the brass outermost. One end of this spiral is attached to the pointer spindle, round which the spiral is wrapped, and the other end is fixed to the free end of the Bourdon. The exposed portion of the capillary as well as the Bourdon tube are at a temperature considerably below that of the bulb. Errors due to this cause are reduced by the use of capillary of very fine bore. When the length of capillary is greater than 20 ft. compensating links may be used. The capillary length is interrupted at intervals by short wider tubes

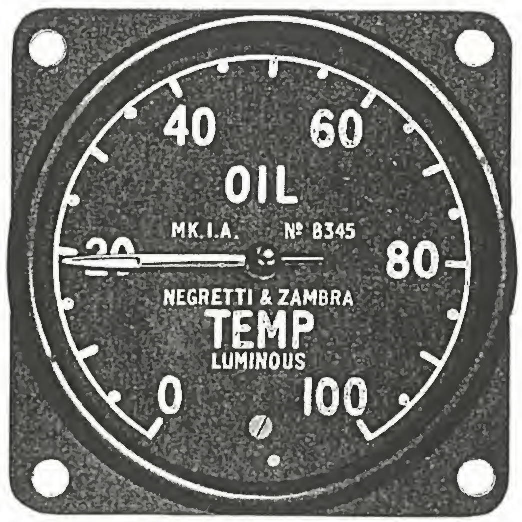


FIG. 21. OIL TEMPERATURE THERMOMETER
(*Negretti and Zambra*)

containing invar rods. When the temperature rises, the tube expands, while the invar remains constant in volume. The volume of the space between the invar rod and the tube increases more than the volume of mercury in the "link," and so compensation is effected by suitably choosing the diameter of the bulb and the lengths of the invar rods. Capillary lengths of 100 ft. and above are thus practicable. Owing to the high pressure in the system, the errors introduced in this type of instrument by change of altitude are negligible. The calibration errors should not exceed 1° C., and errors due to change of temperature between indicator and capillary will not exceed 1·5 per cent for capillaries up to 20 ft., or 2 per cent for those over 20 ft. in length. The lag errors are much less than in the vapour pressure type of thermometer.

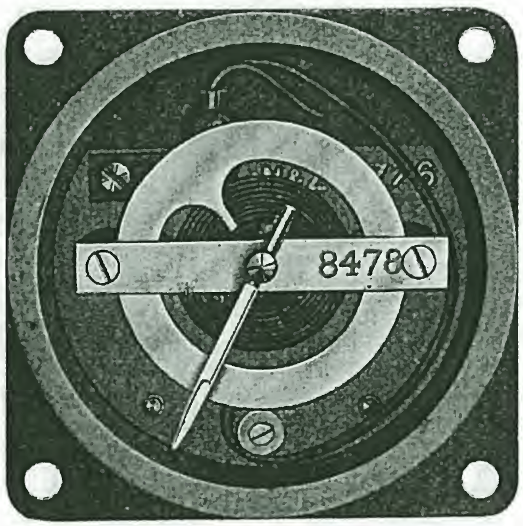


Fig. 22. Interior View of Oil Temperature Thermometer (Dial Removed)

The same precautions in installing the instrument are necessary, as have already been described in connexion with the radiator thermometer. The calibration may be checked in the same way. A correction of 0·05° C. should be made for each foot of difference in level between bulb and indicator. This allowance should be reckoned positive when the indicator is below, and negative when above, the level of the bulb. These figures are given as it may be necessary to test the accuracy of the instrument in the cockpit of the machine.

It should be noted that in order to avoid the risk of fracture of the capillary due to too sharp a bend at the bulb end, it is the usual practice for the capillary to be looped and clipped in the neighbourhood of the bulb end, as illustrated in Fig. 23.

The minimum requirements for Oil Temperature Thermometers are laid down in Civil Instrument Specification No. 6 (see page 128).

The "**Accoson**" types of radiator and oil thermometers—made by A. C. Cossor & Son (Thermometers), Ltd.—are constructed on lines similar to those already described. They work at pressures considerably in excess of normal atmospheric pressure. For example, with a range from 0° to 120° C. the pressure increases from 25 lb. per sq. in. at 0° C. to 640 lb. per sq. in. at 120° C. The effect of change of altitude is therefore negligible. Two liquids are used for filling—one in the bulb, the other in the remainder of the system. They are suitably chosen so that errors due to low temperature are reduced to a minimum.

THE AIR TEMPERATURE THERMOMETER (STRUT TYPE)

As stated on pages 35 and 42, it is necessary to know the temperature of the air, when taking readings of the air speed indicator and altimeter, if

these readings are to be corrected in order to obtain more accurate figures necessary for performance testing, range finding, surveying, or other similar work.

Alcohol-in-glass thermometers are sometimes used for the purpose—the choice of the liquid, alcohol (dyed black or red) depending on its low freezing point (—130° C.) and its high coefficient of expansion which facilitates the design of a large thermometer easily readable at some distance from the cockpit. The instrument which is about 2 ft. in length can be fixed by straps to a strut where it is free from the slipstream. The

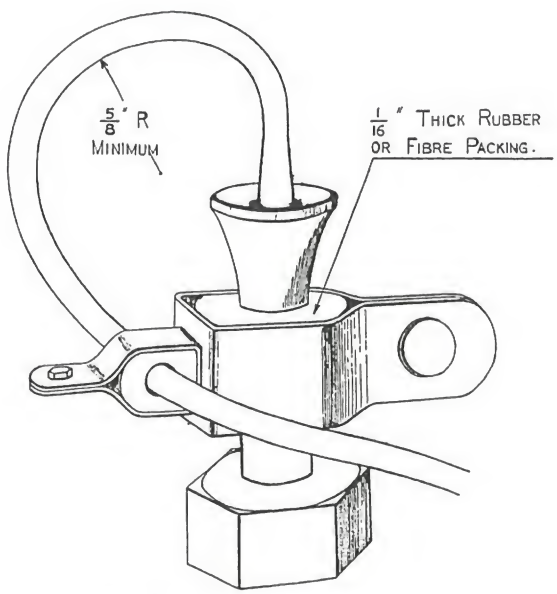


FIG. 23. LOOPING CAPILLARY

bulb is shielded from the direct rays of the sun by a screen, blackened on the interior surface and polished outside. Free circulation of air round the bulb is not interfered with.

THE AIR TEMPERATURE THERMOMETER (TRANSMITTING TYPE)

In the transmitting type air temperature thermometer, a steel bulb (sheathed with copper) is connected by fine capillary tubing to the indicating Bourdon gauge. The whole system is filled with mercury, of which the expansion or contraction during changes of temperature actuates the gauge.

The instrument is provided with a sun shield, and the portion of the capillary in the neighbourhood of the flared outlet at the top of the bulb is looped (as in Fig. 23) to prevent flexing at the joint to the bulb—a point where fracture might otherwise occur, owing to local hardening of the tube during the welding operation. The steel capillary tube is sheathed with braided cotton impregnated with a wax compound. If its length exceeds 20 ft., compensating links are necessary as in the case of the transmitting type of oil temperature thermometers (see page 27).

5. AIR SPEED INDICATORS

A knowledge of the forward speed of the aeroplane is a matter of great importance to the pilot, and the regulations require an air speed indicator to be carried on all aircraft.

An aeroplane is kept in the air by the upward "lift" on the supporting surfaces—the planes. The lift depends on the forward speed of the aeroplane through the air and the angle of attack of the planes to the flow of air past them. If this angle is greater than a certain critical value, lift is lost and at the same time a very high drag or resistance to the forward motion is experienced. The aeroplane then "stalls," and loses height until sufficient forward speed is attained and the attitude of the aeroplane correctly adjusted. The air speed indicator gives a measure of the "lift"

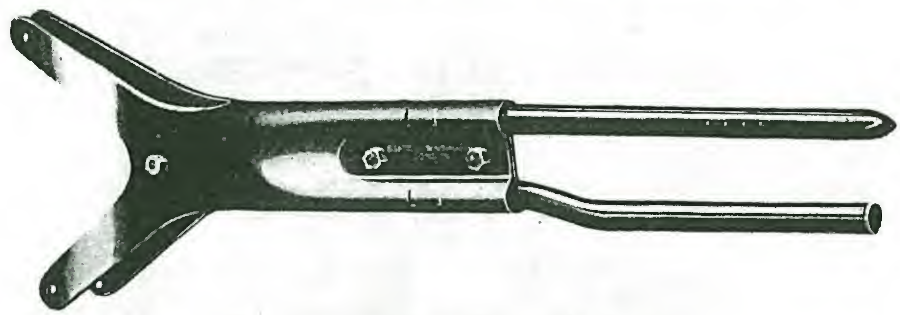


FIG. 24. PRESSURE HEAD (MARK IVA)
(Smith's Aircraft Instruments)

and enables the pilot to anticipate the dangers arising from loss of forward speed. In conjunction with the engine speed indicator, the air speed indicator will give a pilot, who is familiar with his aircraft, guidance as to the fore-and-aft attitude of his machine. Steady readings of both instruments are obtained during level flight in calm air.

The Air Speed Indicator is used to indicate the speed at which the aircraft is moving *relative to the air*. The speed relative to the air must be carefully distinguished from the speed relative to the ground, that is, the speed over the distance travelled as measured on a map. The two quantities are only equal when no wind is blowing. If the reading of the indicator is 80 miles per hour when the aircraft is travelling in the same direction as a wind of, say, 20 miles per hour, the speed relative to the ground will be 100 miles per hour. If the wind is in the opposite direction, the speed relative to the ground (or "ground speed") is only 60 miles per hour.

Civil Instrument Specification No. 2 (see page 122) lays down the minimum requirements for the approval of Air Speed Indicators.

The form of the instrument in most general use is a sensitive differential pressure gauge, mounted on the instrument panel, and connected by lengths of aluminium tubing to a pressure head, attached to a strut on the wing, so as to avoid interference by the slip stream.

The Pressure Head

The standard pressure head (Mk. IVa) comprises pressure and static tubes mounted parallel and close to one another. The pressure tube is open at the forward end which is exposed directly to the wind pressure, and is connected by a length of aluminium tubing to the nipple of the indicator marked *P*. The upper tube, known as the static tube, is closed and coned at the forward end. It is pierced at a short distance from the

end by a series of small holes, and is connected by another length of aluminium tubing to the nipple of the gauge, marked *S*. In tropical climates, where the tube is liable to be blocked by sand and insects, a special "trapped" form of pressure head is used (Mark Va). (Fig. 25.) Detailed drawings of an approved form of Pressure Head accompany Civil Instrument Specification No. 3 (see page 124).

The Mark VIIa pressure head has been specially designed to reduce the risk of ice formation, which would interfere seriously with the functioning of the equipment.

The pressure head is based on the same principle as that used by Pitot about 1730 for measuring the speed of rivers. If a tube closed at one end is placed with the open end facing a stream of air, the pressure inside

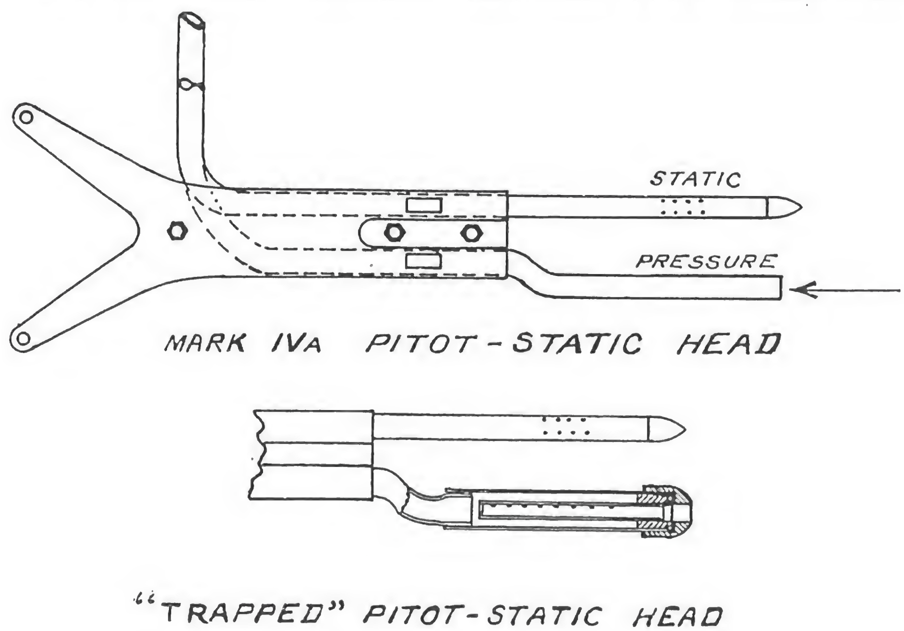


Fig. 25

the tube will be greater than the pressure outside. Suppose the difference of pressure is p, then it can be proved from theoretical considerations that $p = k\rho v^2$, where ρ is the density of the air, v the speed of the air flow, and k is a constant. This formula as it stands, does not allow for variations in density, the effect of which is further discussed on page 34. It gives, however, a measure of the "lift" on the aircraft, and is useful in that the stalling speed is indicated by the same position of the pointer, whatever the density of the surrounding air. The indicating gauge, described below, is used to measure the difference between the pressure in the pressure tube (i.e. that of the wind due to movement of the aircraft through the air) and the pressure in the static tube of the surrounding air, if it were still and undisturbed by the motion of the aircraft, as it is, approximately, in the static tube. The static tube moves through the air in the direction of its axis and without greatly disturbing the air owing to the streamline end. Thus the air passes over the holes in the side of the tube at right angles to their direction. It has been proved by experiment that the pressure inside the static tube is very nearly the true pressure outside whatever may be the velocity of the tube.

The Indicating Gauge

The most usual form of gauge consists of an airtight case, connected to the static nipple, marked *S*. An elastic metal box with thin corrugated sides is fitted inside the case, and its interior connects with the pressure nipple (marked *P*) on the outside of the case. This box is usually made of nickel-silver, and is supported in an aluminium frame carrying a transverse shaft with two short balanced arms mounted across it. One of these arms is connected to the side of the box or diaphragm. The other arm actuates a toothed quadrant by means of a crank. A pinion on the pointer spindle meshes with the quadrant, and the usual hairspring is fitted. The pressure of the air in the pressure tube is communicated to the

FIG. 26. AIR SPEED INDICATOR
(Smith's Aircraft Instruments)

interior of the diaphragm box, and as it varies causes corresponding movements of the pointer, through the mechanism, over the dial. Metal diaphragm instruments such as the type described above give satisfactory performance over a wide range of temperature.

The older type of indicator was fitted with a transverse diaphragm of oiled silk or thin leather, dividing the case of the instrument into two distinct airtight compartments connected respectively with the pressure and static nipples on the exterior. Changes of pressure cause movements of the diaphragm, which are communicated to the pointer by suitable mechanism. A disc, with a central spindle, is fitted to the centre of the diaphragm. The end of the spindle is in contact with a leaf-spring actuating a bell-crank lever, one arm of which projects through a slot in a metal plate pivoted on an axis parallel to the pointer spindle. A quadrant, forming one end of this plate, engages a pinion on the pointer spindle.

An indicator with an oiled silk diaphragm is very sensitive, but its useful life is short, especially if subjected to high temperatures. The material is not suited to tropical conditions. On the other hand, instruments with metal diaphragms are not seriously affected by changes of temperature.

Great improvements have been made in recent years in the construction of metal diaphragms and diaphragm boxes. Nickel-silver (Grade A) is usually employed, and after rolling is pressed into the desired shape, so that the minimum amount of solder is necessary to close the box finally. The solder must be applied only at the extreme edge of the box to avoid interference with its elastic properties. The nickel-silver disc is usually rolled to a thickness about 16 per cent above the final thickness. It is then annealed and rolled and cross-rolled by stages, to eliminate the effect of grain and

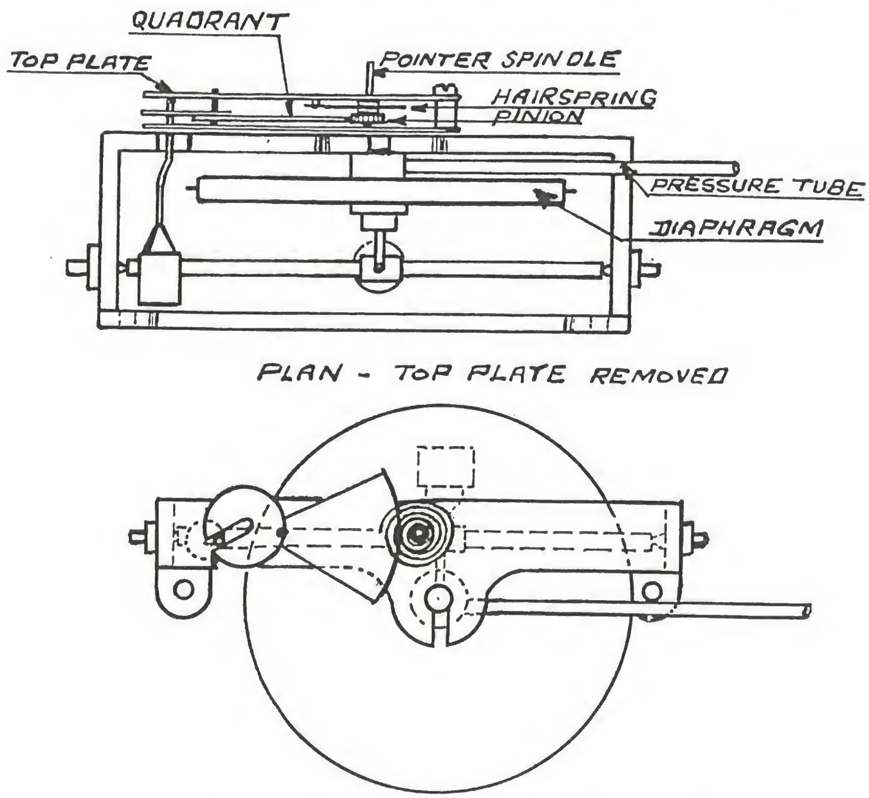


FIG. 27. AIR SPEED INDICATOR MECHANISM

reduce the risks of cracking during the pressing process, until the final thickness is obtained. Corrugated diaphragms are formed in a press with a single die, a rubber sheet being interposed between the disc and the plunger of the press. The diaphragms are aged before use.

Whatever the material of the diaphragm, it is essential that the cases of the indicators be airtight. This is effected by providing a rubber ring which can be compressed by screwing up the bezel ring. Leakage on the pressure side may introduce serious errors in readings. Small leaks on the static side may be permitted. (See, however, page 116.)

It should be noted that the speed indicated is that of the pressure head, and if the head is fixed at some distance laterally from the centre line of the machine, as is usually the case, errors will be introduced during turns, when the wing on the outer edge of the curve moves faster than the inner wing. However, the errors introduced are not serious except on very sharp turns.

Problems of Calibration

The dial of the indicator is calibrated so as to read directly in miles per hour or in knots (1 knot = 1·152 m.p.h.). It has already been stated that, in general terms, the pressure difference operating the mechanism is proportional to the square of the air speed. The pressure difference is usually expressed in millimetres of water—namely the height in millimetres of a column of water which would produce the same pressure.

Now if p = the pressure difference in millimetres of water
ρ = the density of air in grm./c.c.
g = the acceleration due to gravity in cm./sec.^{2}
d = the density of water in grm./c.c.
c = the constant for the pitot-static head
v = the speed of the air in miles per hour

it can be shown that

$$p = \frac{9992{\cdot}24 \,.\, \rho \,.\, c}{gd} v^2$$

It remains to substitute values of ρ, c, g, and d. Substituting $\rho = {\cdot}001221$, $c = 1$, $g = 980{\cdot}62$, and $d = {\cdot}99912$, we find that $p = {\cdot}01243v^2$, or if v is measured in knots, $p = {\cdot}01648v^2$. The value for ρ is an average value obtained by experiment.

Recently, the adoption of the International Standard Atmosphere has resulted in the density of the air being reckoned on a new average basis, and taking the new value ·001226 we obtain

$$p = {\cdot}01250\, v^2 \text{ (miles per hour) and } p = {\cdot}01658\, v^2 \text{ (knots).}$$

Most modern air speed indicators are calibrated on this uniform basis. The International Standard Atmosphere is used as a reference atmosphere in aircraft performance tests, and all figures of performances can be reduced to what they would have been had the atmosphere been standard at the time of the tests. The full details of the scheme are given in the Official Bulletin, No. 7 (O.B.7), of the International Commission for Air Navigation.

By substituting values for v in the formulae quoted above, the corresponding pressures in millimetres of water can be obtained. These can be set out in the form of a calibration table.

Corrections

At high speeds (above 200 m.p.h.) it is necessary to correct the figures for compressibility of the air.* The method of calibration already described

* The formulae then used are—
$p = {\cdot}01250 \,.\, v^2 (1 + 0{\cdot}43\, v^2 \times 10^{-6})$ m.p.h.
and $p = {\cdot}01658 \;\; v^2 (1 + 0{\cdot}57\, v^2 \times 10^{-6})$ knots.

For comparison, the corresponding pressure differences at four speeds are set out in the following table—

Air Speed m.p.h.	Pressure difference in mm. of water using Standard head		
	On old density basis	On new density basis	Corrected for Compressibility
80	79·6	80·0	80·2
100	124·3	125·0	125·6
150	279·7	281·3	284·0
200	497·2	500·1	508·7

assumes that the density of the air is uniform and equal to the value given above, either on the old or the new basis. Now the true density of the air depends on both the temperature and the pressure, both of which decrease as the aircraft gains height. The distribution of the temperature and pressure in the atmosphere is a complex problem. From data collected over a long period, it has been found possible to provide formulae from which the values of pressure and temperature can be calculated at any given height. The results are only approximate, as local variations are not taken into account, but they serve for all practical purposes.

The errors to which instruments are normally subject, such as those due to temperature changes, are considerably greater than those due to the use of the approximate formulae. The same formulae are used to reduce experimental measurements to standard atmospheric conditions in order that they may easily be compared with each other.

The earlier "isothermal law" for the distribution of temperature and pressure assumed that the temperature was constant at all altitudes. The I.C.A.N. convention assumes that the temperature falls 1·98° C. for every thousand feet rise up to about 30,000 ft., and thereafter remains at a constant value.

Computers in the form of a circular slide-rule are used for correcting air speed readings when great accuracy is required. (See also p. 100 and Appendix VI.)

Although the present form of air speed indicator has been improved considerably of recent years there is pressing need for an instrument in which automatic compensation is made for changes in altitude and atmospheric pressure.

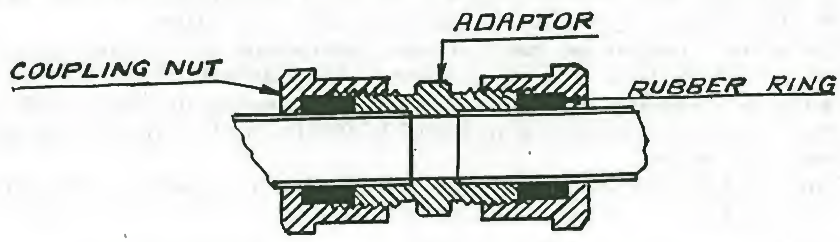
Installation

The installation of an air speed indicator must be carefully carried out. The pressure head (pitot-static head) should be placed in a position as free as possible from air disturbance. At the same time it must be conveniently situated so as not to be liable to accidental damage. The best position has been found to be about two-thirds of the way up the outer front inter-plane strut. It should be adjusted so as to be horizontal when the main plane chord is inclined about 3° to the horizontal. This adjustment minimizes the variations due to change of trim as the speed is varied. The variations are not serious for angles less than 10°. The edge of the pressure tube must be smooth and circular, and the small holes in the sides of the static tube must be free from burrs or dirt, which would prevent the air inside from quickly taking up the average pressure of still air. The head should be placed so that the pressure (bent) tube is below the static tube. The "set" in the pressure tube is introduced so that as much moisture as possible will drain off. The "trapped" pressure head, if used, should be unscrewed and cleaned periodically. Care must be taken to ensure that it is correctly reassembled with the word "top" uppermost. Finger pressure only should be used to tighten the knurled brass cap in order to avoid straining the tube and joints.

The aluminium connecting tubing should be run inside the wing or fuselage as far as it is possible to do so. It is important to avoid all restrictions in the pipe lines, which would produce false readings. If joints are necessary, special attention must be paid to ensure that the joint is airtight. There are several types of joint in use. In one method, the ends of the tube, filed smooth to face at right angles to the axis of the tube, are butted together and sleeved by a short length of tubing of slightly larger diameter which fits closely. The joint is completed by short lengths of

rubber tubing allowing overlaps of at least 1 in. Owing to the rapid deterioration of rubber, especially in tropical climates, such joints need to be remade periodically.

Joints can be made with all metal fittings. The ends of the tubing to be joined are inserted in an "olive"—a short piece of aluminium tube tapered at the ends. This is tightly gripped on to the butted ends of the tubes by coupling nuts which are screwed on to a sleeve. The screw threads are tapered so that a very tight grip is obtained. This joint suffers from the disadvantage that the olive bites into the ends of the soft aluminium tube, which must be cut away if it is necessary to disconnect and remake the joint. An improved form of this joint is in use. A rubber ring and a special coupling nut are slipped over the ends of the tubes to



AIR SPEED INDICATOR PIPE LINE JOINT

FIG. 28

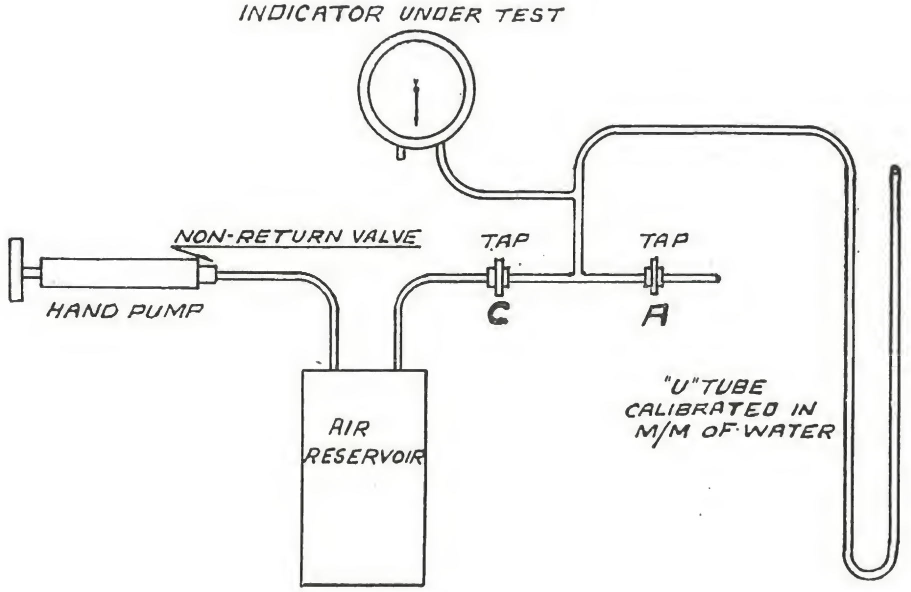
be joined, and an adaptor made of duralumin is fitted over the ends. On screwing up the nuts, the rubber rings are held tightly compressed, and make an airtight joint. (See Fig. 28.)

From time to time the tubing must be disconnected from the instrument and the head, and condensed moisture and dirt blown out by a stream of air from a pump. A test for leaks may be applied to the system as installed. A simple method is to attach a short piece of rubber tubing to the pressure head tube and to blow *gently* down the tube until the indicator gives a reading of, say, 100 m.p.h. The rubber tube is then pinched and the indicator watched to see if the pointer moves back towards the zero. If a leak manifests itself the indicator should be disconnected and tested separately in the same way to determine if there is a leak in the diaphragm. If not, the leak will be located in the pipe-line. The static side can be tested similarly by gently sucking air out and pinching the rubber tube. In each case the tube should not be less than 10 in. in length in order to avoid the deposition of moisture from the breath.

When the indicator has a "floating" zero, the position of the pointer is not determined by any stop in the mechanism. Normally the pointer is approximately vertical (either up or down) when no pressure is applied. Thus, an error in calibration is indicated if it assumes any other position.

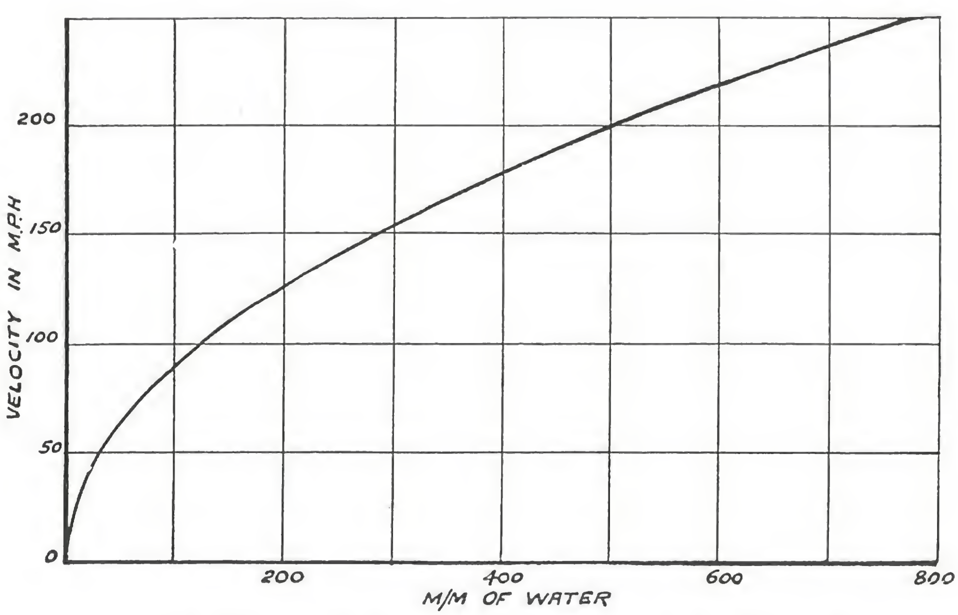
Check on Accuracy

A simple U-tube manometer may be used to check the accuracy of the gauge if this is suspected. The apparatus is shown in the sketch (Fig. 29). Pressure from the air reservoir can be applied both to the manometer and the instrument under test by means of the T-joint. The water in the manometer is adjusted to the zero marks and the tap *C* is closed. Air is then pumped into the reservoir by the pump—a rubber bulb fitted with a non-return valve may be used—and the tap *A* closed. The tap



CHECK TEST ON AIR SPEED INDICATOR

Fig. 29



MARK IVA AIR SPEED INDICATOR — PRESSURE IN M/M OF WATER EQUIVALENT TO VELOCITY IN M.P.H — $P = 0{\cdot}01249\,V^2$

Fig. 30

C is then cautiously opened, thus applying pressure to the manometer and the instrument at the same time. The pressure is measured in millimetres of water by the difference in level in the arms of the U-tube. The error, if any, is found by reference to a calibration table. It is convenient to graduate the U-tube directly to read miles per hour. The curve (Fig. 30) will serve to give some idea of the relation between the miles per hour readings and the "head of water" measured in millimetres. The tap C is conveniently made as a three-way tap, providing an opening direct to the atmosphere, so that the pressure can be reduced when necessary.

The instrument should be accurate to within plus or minus 2 m.p.h. at ordinary room temperature with the dial vertical. (See p. 123.)

The same pressure head may be used to actuate two or more indicators, in the pilot's cockpit and the passenger cabins, by using T-joints to join up each indicator with the pipe-lines.

Tests

Accurate tests of an air speed indicator can only be carried out on a sensitive manometer, which is itself checked periodically by means of a reference standard.

The manometer consists essentially of two concentric cylinders containing water, which is free to pass from one to the other through openings at the bottom of the inner cylinder. The outer cylinder is closed and provided with a tap so that air under pressure can be introduced, thus lowering the water-level in the outer cylinder and raising the water-level in the taller inner cylinder. Another tap opens to the atmosphere, and is used when it is necessary to release the pressure. A float on the water in the inner cylinder is connected by a chain operating on a spiral arbor fixed to a pointer spindle in such a way that the chain is either wound up on the spiral or unwound from it, according to the direction of motion of the float. The pointer moves over a dial calibrated in millimetres of water, miles per hour, and knots in concentric scales. The form of the spiral arbor is chosen so that the scale is as open as possible at the lower readings, where the movement of the pointer would be otherwise small.

For precise adjustment of the zero, there is provided a screw displacement plunger working in a small cylinder fixed to the side of the outer cylinder, and communicating with it by a tube in which is fitted a tap.

Connexions are provided for the instruments under test, and the pressure is obtained by means of a pump with a capacity reservoir. Control valves are conveniently placed for the operator. In carrying out a test, the valve controlling the pressure is opened so as to allow the pressure to increase until the pointer of the instrument under test has covered the whole range and returns to the datum-mark, if any. The pressure is then decreased by gradually opening the valve which is open to the atmosphere, until the pointer again reaches zero. During the process the behaviour of the pointer is watched. It should move smoothly and freely over the scale without sticking, and should consistently stand at the same distance from the dial throughout the movement. It should not be so far from the dial as to cause serious parallax errors, nor so near to the glass as to risk contact. The zero reading should be checked against the sub-standard manometer and the pressure gradually increased in steps, so that the pointer of the manometer stands successively at convenient scale divisions corresponding to exact multiples of 1 m.p.h. The error of the instrument under test at each point is read off and recorded. After reaching the maximum reading, down readings are taken in the same way, under gradually diminishing pressures.

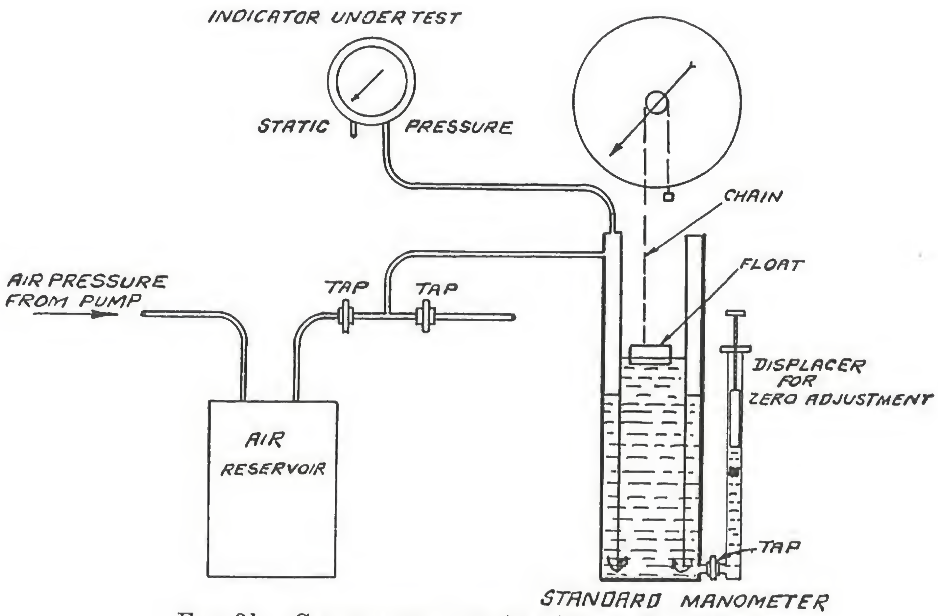


Fig. 31. Calibration of Air Speed Indicator

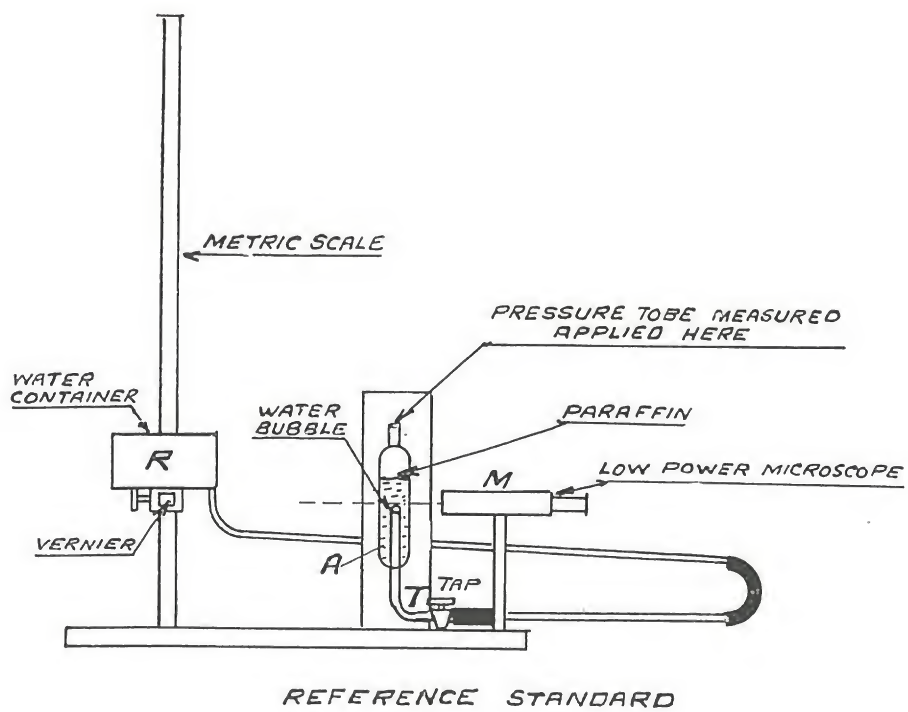


Fig. 32

The "**Reference Standard**" (Fig. 32) is essentially an elaborate form of U-tube manometer, used to measure a "head of water" very accurately. The water container is counterpoised and moves vertically against a specially calibrated metric scale. It is connected by flexible tubing to a fixed glass bulb, and the level of the water inside can be made to coincide with the axis of a low-power microscope, which is positioned in the horizontal plane containing the zero of the scale. A layer of paraffin prevents evaporation and renders it easier to observe the meniscus and take an accurate reading. In use, the position of the reservoir is adjusted until the head of water balances the pressure applied and the bubble meniscus appears on the axis of the microscope. The pressure is measured directly in terms of millimetres of water by the reading on the scale, which is provided with a vernier and can be read to an accuracy of 0·1 mm.

Pressure differences in millimetres of water corresponding to various speeds in miles per hour, are given in the following table.

Air Speed m.p.h.	Pressure difference mm. of water	Air Speed m.p.h.	Pressure Difference mm. of water
50	31·29	140	247·1
60	45·08	150	284·0
70	61·4	160	323·6
80	80·24	170	365·8
90	101·6	180	410·7
100	125·6	190	458·4
110	152·1	200	508·7
120	181·2	250	802·4
130	212·8	300	1166·0

The above figures are corrected for compressibility (see footnote p. 34).

6. INCLINOMETERS

The Cross Level

The Cross Level is used primarily to show the angle of inclination of the lateral axis of the aircraft to the horizontal.

The ordinary form of cross level is a curved glass tube mounted in a suitable aluminium frame with the convex outer side uppermost. The

FIG. 33. CROSS LEVEL (MARK IVA)
(Smith's Aircraft Instruments)

tube contains a non-freezing liquid enclosing a small bubble, which always tends to remain at the highest point of the tube owing to the fact that its density is small compared with that of the liquid. As the tube tilts when the aircraft banks, the bubble will move always so as to keep at the highest point. The displacement of the bubble from the centre therefore gives a measure of the tilt. There are fixed marks or points on

the frame showing the position of the centre of the bubble for angles of tilt of 10 and 20 degrees on each side of the vertical. Thus, the cross level indicates the angle at which the lateral axis of the machine is inclined to the horizontal in straight flight. It also serves as a banking indicator to inform the pilot when a turn is correctly banked. In this case the bubble will remain in the central position. In turning, therefore, the pilot watches the bubble and endeavours to keep it central by appropriate movements of the control column, thus avoiding side-slips. The control must always be moved in the direction of the bubble. Hence the rule: "Follow the bubble." This will be clear if the forces acting on the liquid are considered.

In straight flight, under the action of gravity the bubble will be central when the aircraft is flying level. The bubble will move to the right of the instrument if the left wing dips, and to the left if the right wing dips.

If the aircraft turns and the turn is correctly banked, centrifugal force comes into play and tends to keep the bubble central. If the turn is over-banked, the aircraft side-slips inwards in the direction of the resultant force. The result is that the bubble moves outwards. If the turn is under-banked, however, the aircraft side-slips outwards and the bubble moves inwards.

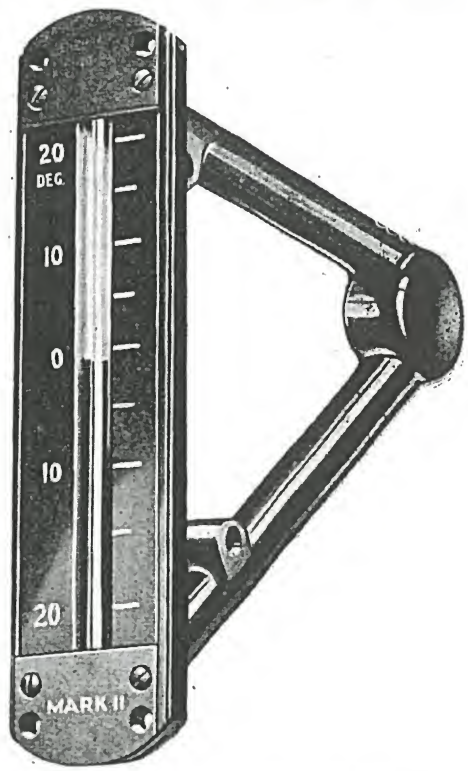


FIG. 34. FORE-AND-AFT LEVEL (MARK IIA)
(Smith's Aircraft Instruments)

Two types of cross-level are used on civil aircraft. Mark Va has a blue band running along the back of the tube. Owing to refraction effects of the liquid, the blue band is not seen except just where the bubble happens to be, so that movements of the bubble are clearly seen against the white backing. A small electric lamp at one end of the frame serves to illuminate the bubble. This type is liable to burst if subjected to high temperature, and at low temperature the liquid may contract unduly, forming too large a bubble. Mark VII type is provided with an expansion bulb connected to the tube at one end by a short capillary. At normal temperature the tube is full of liquid, the bulb is about one-third full, and the bubble is about half an inch long. This type is specially used in tropical climates where wide ranges of temperature are experienced, and with the above proportions the size of the bubble remains fairly constant over a wide range of temperatures. If it is necessary to increase the size of the bubble, the instrument should be grasped by the lamp-end and swung at arm's length with a quick circular movement. Some of the liquid will be driven into the expansion chamber. The size of the bubble may be decreased by grasping the tube by the other end and swinging as before.

The instrument is mounted on the dashboard, so that the centre of the bubble is exactly opposite the zero mark when the aircraft is level and in flying attitude. It should be placed centrally and as nearly as possible on a level with the pilot's eye.

The Fore-and-aft Level

The Fore-and-aft Level is used to indicate the inclination of the longitudinal axis of the aircraft to the horizonal. It consists of a continuous closed glass tube of triangular shape fixed in an aluminium case, so that one side of the triangle can be seen through a slot in a scale plate fitted to the front of the instrument. A constriction in the lower limb damps out surges in the liquid. The glass tube contains a sufficient amount of coloured liquid to rise half-way up the exposed part of the tube and stand at the zero mark, when the aircraft is flying level. The tube is graduated in degrees both above and below the zero mark. During a climb the level of the liquid rises, and an indication of the tilt is given on the scale above the zero. During descent the liquid falls, and the inclination of the longitudinal axis of the aircraft is indicated in the part of the scale below the zero mark.

It should be noted that the instrument will give reliable indications of angles of climb (or dive), only when the aeroplane is climbing (or diving) steadily. The level of the liquid is affected by sudden changes in inclination, namely, during accelerated motion or the reverse.

7. HEIGHT INDICATORS OR ALTIMETERS

The altimeter is used to give an indication of the height of the aircraft above the ground level. The instrument in most general use is very similar in construction to the aneroid barometer, which actually measures the pressure of the atmosphere, that is, the pressure due to the weight of a column of air of unit area and whose height is that of the atmosphere. It is this pressure which is balanced by the pressure due to the mercury in an ordinary mercury barometer, and is usually expressed in inches or millimetres of mercury. The pressure is due to the weight of air above, and gradually decreases as the height above the earth's surface increases. If the air were always still and uniform in its composition and distribution, and not affected by any other influence but its own weight, the pressure due to the weight of the air would be an exact measure of the height above the surface of the earth. As these conditions do not hold, determination of accurate height is no easy matter. It necessitates exact knowledge of air temperatures and pressures at various heights. The average pressure at ground level is about 30 in. of mercury, or 14·75 lb. per sq. in., or 1,013 millibars. The meteorological unit of atmospheric pressure is the **Bar**, which is equal to a pressure of 1 megadyne per sq. cm. The millibar is a thousandth part of the bar, and is, therefore, equal to a pressure of 1,000 dynes per sq. cm. Its practical equivalent is 27 ft. of air at sea-level. The following conversion is a useful one to remember: Pressure due to 1 in. (or 25·4 mm.) of mercury (under standard conditions, namely at 0° C. and at mean sea-level in Latitude 45°) is equivalent to 33·9 millibars. Observations of pressure and temperature at various heights at different times of year have been recorded, and from them formulae have been evolved from which it is possible to calculate the height, approximately, from (1) a knowledge of the pressure at that height, (2) the pressure at ground level, and (3) the difference in temperature between these two points. Allowance is made for the temperature variation by adopting the I.C.A.N. convention of variation as explained in the

section on air speed indicators (p. 34). Both the I.C.A.N and Isothermal conventions, however, give only approximate results, but the I.C.A.N. convention more accurately represents average conditions all over the world. (See Appendix VI.)

The following table shows the height in feet, corresponding to barometer readings in inches, on both the Isothermal and I.C.A.N. conventions,

Fig. 35a. Altimeter (Mark V)
(Smith's Aircraft Instruments)

under standard conditions, namely at 0° C. and in Latitude 45° (29·92 in. = 760 mm.).

Table Showing Height in Feet Corresponding to Readings of the Barometer in Inches

Height feet	Barometer Inches	
	Isothermal	I.C.A.N.
0	29·92	29·92
1,000	28·84	28·86
2,000	27·80	27·82
3,000	26·79	26·82
4,000	25·83	25·84
5,000	24·89	24·90
10,000	20·71	20·58
20,000	14·34	13·75
30,000	9·92	8·89

Before dealing with the calibration, however, a description of the instrument will be given.

The Instrument

The instrument is a barometer constructed on the aneroid principle, and contains a round, flat, metal box with corrugated sides, which is exhausted of air and sealed. In a very common type of construction (which, however, is becoming obsolete) one side of the box is fixed securely to the base plate, and the other side to a leaf-spring, which prevents the box collapsing under the atmospheric pressure outside it. Variations of air pressure, such as are experienced during a flight as the aircraft rises or falls, cause small movements of the side of the box attached to the leaf-spring. The movements of the spring and the box amount to not more than one-tenth of an inch, and, after magnification by a long, straight lever, and a bell-crank lever, are communicated to the pointer by a chain, arbor, and spindle. A hairspring is fitted to take up backlash and keep the chain taut. The dimensions of the parts are arranged so that the pointer moves over an evenly divided scale on the dial, and makes about one and a quarter revolutions. The dial, on which the heights are marked, can be rotated by means of a pinion (worked by a knurled head) meshing in teeth on the outer rim of the dial, and is set to read zero for sea-level before a flight. The height indicated during the flight will then be that above sea-level (not ground-level), provided that no change in the barometric pressure takes place during the flight. The instrument is compensated for temperature changes at ground pressure only by a compound brass-steel connecting link incorporated in the mechanism. Owing to unequal expansion of the two metals this link assumes a curved shape if the temperature is varied. Its effective length is unaltered and the readings consequently unaffected. This compensation will be referred to later when errors of altimeters are dealt with. In order that the instrument may respond to changes of pressure, the case of the instrument is *not* airtight, and in some types of altimeters is provided with a small hole open to the atmosphere.

The following types of altimeter are approved for civil aircraft—

Mark V . . .	Range	16,000 ft. by 100 ft.
Mark Va . . .	,,	20,000 ft. by 200 ft.
Mark Vb . . .	,,	26–28,000 ft. by 100 ft.
Pioneer No. 355 . .	,,	20,000 ft. by 200 ft.

Civil Instrument Specification No. 1 (see p. 120) lays down the minimum requirements.

The K.B.B.-Kollsman Sensitive Altimeter

This instrument (Fig. 35B) is actuated by an aneroid unit fitted with a geared mechanism which moves three pointers of different lengths over a common scale. The longest pointer completes one revolution for every 1,000 ft. change of altitude and the scale is graduated in hundreds of feet. Another smaller pointer indicates the number of revolutions of the largest pointer and therefore thousands of feet. A still smaller pointer indicates tens of thousands of feet. The widely spaced graduations enable small differences of altitude to be observed, a difference of 5 ft., one-quarter of a scale division being immediately apparent. Lag is reduced to such an extent that the pointers return to zero, within less than 10 ft. after a descent from 10,000 ft. at the average rate of 1,000 ft. per minute. Provision is made for connecting the case of the instrument to the static line of the air speed indicator to avoid errors due to differences between the pressures in the cockpit and the external pressure. Temperature compensation is such that at low altitudes, the error due to temperature

amounts to a fraction of a foot. Thus the instrument is suitable for use as a landing altimeter. Adjustment for variation in atmospheric pressure is made by rotating a knob at the lowest part of the instrument case. This causes rotation of a short scale of millibars (or inches) visible through a small aperature in the dial. The scale can thus be set to a fixed reference mark. Any slight change in the zero due to slow release of internal stresses in the diaphragm can be detected by setting the pointer to zero and comparing the reading of the auxiliary barometer scale with that of the standard barometer. By loosening the zero-setting screw (seen just to the left

FIG. 35B. K.B.B.-KOLLSMAN SENSITIVE ALTIMETER

of the knob in Fig. 35B) the knob can be pulled outward and turned so as to move the barometer scale only, until the reading corresponds to that of the standard barometer. The knob is then pushed home and the setting screw replaced.

Errors of Altimeters

The aneroid barometer, or altimeter, may undergo considerable changes occupying in some cases quite long periods of time. These changes are, however, dependent on the type of instrument, and the care and attention paid to its design and construction. This must not be taken as an indication that the altimeter is generally an erratic and unreliable instrument, as although there are many errors which are variable in character, these errors in a good instrument can be attributed to definite physical laws, and consequently very close allowances and corrections for them can be made.

Altimeter errors can be briefly classified as follows—

(*a*) Errors due to the instrument not being in a physically stable state. These can be avoided by waiting long enough before readings are taken.

(*b*) Errors due to changes taking place over a considerable period. These are due to the gradual settling of the parts as is frequently found with instruments manufactured hurriedly and put into service before a reasonable ageing period has been allowed. These errors need not be serious if the instruments are checked against reliable standards from time to time, and adjusted as necessary.

(*c*) Inherent errors, due to faulty or imperfect design or construction, and due to the physical properties of the materials used in construction.

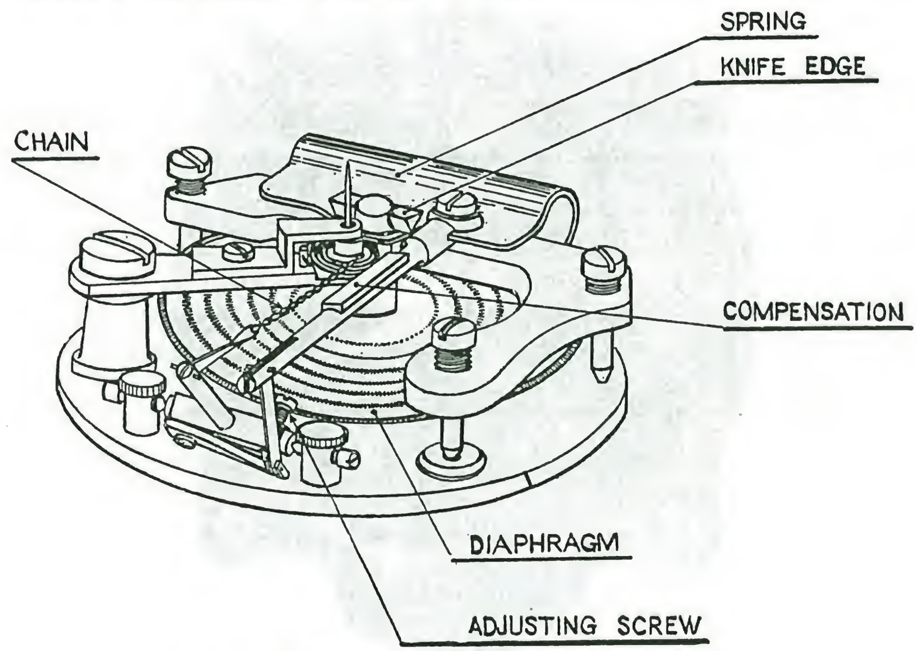


FIG. 36. DIAGRAM OF ALTIMETER MOVEMENT

Under this heading may be included temperature errors and the effect of temperature on the elasticity of the diaphragm and spring. An attempt is made at compensation by the incorporation of the bimetallic arm previously described, but this chiefly affects changes in temperature at ground pressure, and does not allow for changes in stiffness of the elastic system under low pressure conditions. Among the inherent mechanical errors are those due to friction or backlash in the moving parts (e.g. the linkwork), and lack of balance of the moving parts. These errors can be reduced to a minimum in service by using the instrument in the same position in which it has been tested, and by tapping the instrument lightly during testing. (Tapping should not be more violent than the equivalent of normal aircraft vibration.) Further errors result from the imperfect elasticity of the spring and diaphragm combination, resulting in (*a*) "Creep," or the gradual increase of reading which takes place when an instrument is maintained in a constant low pressure condition for several hours, and (*b*) Hysteresis, or "Lag," which is the excess of the "down" readings (taken as the pressure is increasing) over the "up" readings (taken as the pressure is decreasing). (See p. 48.)

This type of altimeter has been described and its sources of error fully discussed since it is the type which the ground engineer is most likely to meet with in the course of his work.

Of recent years great improvements have been made in the design of altimeters, resulting in reduction of lag; at the same time automatic compensation is made for errors due to the effect of change of temperature upon the elasticity of the spring and diaphragm at different altitudes. In these instruments the diaphragm boxes are constructed of selected material which is subjected to special treatment as described in the section on Air Speed Indicators (p. 33). They are evacuated to a pressure approximately that of $\frac{1}{4}$ mm. of mercury. A better method of supporting the spring has

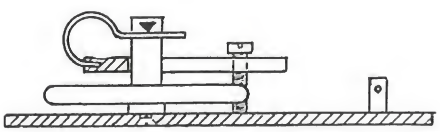


FIG. 36A

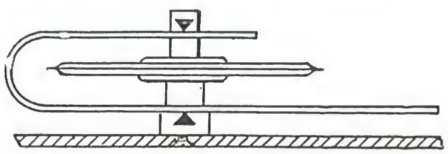


FIG. 36B

been introduced (see Fig. 36B) and the diaphragm box is supported entirely on knife edges. The older method of mounting is shown in Fig. 36A for comparison.

In modern instruments, compensation for errors due to change of temperature is effected by fitting a compensating helix to the pointer. The helix is made of "invar" steel and brass, and is so constructed that a rise in temperature causes it to coil more tightly owing to the greater coefficient of brass as compared with that of steel. Thus the pointer spindle is turned in a clockwise direction and counteracts the movement in the opposite direction due to the contraction of the spring.

Installation

The altimeter should be fitted to the instrument panel with the dial in a vertical plane, and the adjusting knob at the bottom of the instrument. If it is mounted in an horizontal position, its errors and behaviour should be known in this position, or inaccuracies may be introduced, and the effect of vibration may be increased. The adjusting knob should work smoothly. No attempt should be made to force it, or the teeth may be stripped from the pinion of the spindle. Repairs to the instrument should only be carried out by a trained instrument mechanic. If the pointer is not in the approximately vertical position in the types of instruments mentioned above, the accuracy should be suspected. The instrument has probably been dropped or received some sort of jar.

Mention has been made of the fact that the case should not be airtight. A small hole may be drilled in the instrument case allowing the instrument to record the external pressure. Altimeters in enclosed compartments are subject to errors due to difference between the pressure inside the compartment and that of the pressure of undisturbed air outside. This difference of pressure (which may cause an error amounting to as much as 150 ft.) may be observed during flight by a movement of the pointer, when a window in the neighbourhood of the instrument is suddenly opened. The error increases as the speed of the aircraft increases and decreases slightly as the height increases. To reduce this error, altimeters are often fitted with an airtight case connected to the static side of the air speed indicator installation. It is essential that the altimeter case as

well as the connections to the static side should be free from leaks in order to ensure that no serious error is produced in the reading of the air speed indicator. The usual tests for leaks should be applied after connecting up to the case of the instrument. No leak is permissible on the pressure side, and the leak, if any, on the static side should not be greater than that indicated by a movement of the pointer from the 150 m.p.h. mark to the 135 m.p.h. mark in 10 seconds.

Tests on Altimeters

In some altimeters a lubber mark is painted on the bezel plate to indicate the position of the pointer at standard barometric pressure. The letters S.B.P. are painted alongside the mark, which serves as a zero and is useful when taking off from aerodromes in elevated and tropical localities.

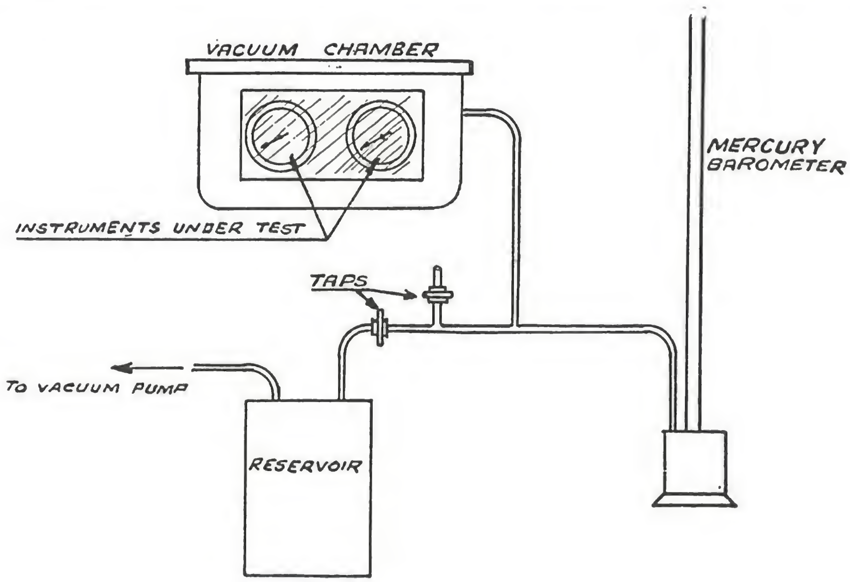
A test on the accuracy is made by placing the instrument in a chamber from which the air can be exhausted gradually by means of a suitable pump. A capacity reservoir is introduced to prevent sudden changes of pressure, and an accurate mercury barometer is connected to the vacuum chamber to show the pressure at any instant. The barometer is conveniently provided with scales, inches of mercury on one side and equivalent thousands of feet on the other. In many types, owing to lag errors, after a rapid descent from, say, 20,000 ft. the pointer may indicate 300 ft. instead of zero. After a minute or two this may reduce to 100 ft., but an hour or two at least must elapse before the pointer returns to zero. For this reason, tests are usually made at the standard rate equivalent to a rise or fall of 1,000 ft. per min. in one continuous test. Under these conditions the permissible errors vary according to the particular point of the range. The following figures are approximate—

PERMISSIBLE ERRORS FOR ALTIMETERS

	0/28,000 ft.		0/20,000 ft.		0/16,000 ft.	
	Up	Down	Up	Down	Up	Down
0	0	+ 225	0	150	0	150
1,000	− 60	+ 270	− 40	+ 160	− 40	+ 160
2,000	− 90	+ 310	− 60	+ 180	− 60	+ 180
3,000	− 120	+ 350	− 70	+ 190	− 70	+ 190
4,000	− 140	+ 370	− 80	+ 200	− 80	+ 200
5,000	− 150	+ 400	− 80	+ 230	− 80	+ 230
6,000	− 160	+ 420	− 90	+ 250	− 90	+ 250
7,000	− 170	+ 440	− 100	+ 280	− 100	+ 280
8,000	− 180	+ 460	− 110	+ 300	− 110	+ 300
9,000	− 190	+ 480	− 110	+ 320	− 110	+ 320
10,000	− 200	+ 490	− 110	+ 330	− 110	+ 330
15,000	− 240	+ 510	− 140	+ 400	− 140	+ 400
16,000	− 250	+ 510	− 150	+ 400	− 150	+ 400
20,000	− 300	+ 490	− 200	+ 400		
25,000	− 390	+ 420				
28,000	− 500	+ 350				

A mercury barometer will remain accurate for a considerable period, but an error is gradually introduced by the very gradual in-leakage of

air in the mercury. A test for air in the vacuum space above the surface of the mercury at the top of the column may be made in the following way. The whole tube is gradually inclined away from the vertical. If no air is present, the mercury will completely fill the space, coming against



ALTIMETER TESTS

FIG. 37

the top of the glass tube with a metallic "click." If air is present, it will act as a cushion for the mercury, and a small bubble of air may be observed if the top of the glass tube is visible. Great care should be taken not to incline the barometer too suddenly, or the mercury may rush to the top of the tube and cause fracture. If air is present, the barometer should be returned to the makers for overhaul.

Check Against a Sub-standard Altimeter

If a small vacuum chamber and an exhaust pump are available, the altimeter may be checked against a sub-standard by placing both instruments in the chamber and exhausting the air. (See Fig. 37.) The readings at various points of the scale may then be compared. In making these comparisons, the corrections (supplied with sub-standard instruments) must be applied. The rate of change of pressure, whether increasing or decreasing, should not exceed 1,000 ft. per minute.

Testing of Altimeters

Altimeters of the rotatable dial type are usually tested not only over the range marked on the dial but over the whole range of pointer movement which may be experienced in actual use. This complicates the test in a way which must now be discussed.

Tests are conveniently carried out by means of a standard mercury column calibrated in inches of mercury as well as in equivalent heights according to the isothermal or I.C.A.N. conventions.

Consider a reliable instrument, which has been set to read zero at sea-level when the barometric pressure is the standard pressure of 29·99 in. (London Laboratory Conditions.) (See p. 96.) Provided the barometric pressure remains at this value during a flight, the instrument will give the height above sea-level, assuming that the various sources of error are left out of account.

The barometric pressure, however, is seldom equal to the standard pressure. If the barometer is "high" on the occasion of some subsequent observation at sea-level, the pointer shows a reading below the zero of the scale: if "low," above zero. This is equivalent to a shift of the whole scale in one direction or the other. It is therefore desirable to test the instrument at pressures slightly above and below the normal range of the scale.

One method of test is as follows—

The reading of the barometer at the time of test is taken from the height scale and noted in terms of feet. Let us suppose it is + 160 ft.

(The plus sign indicates a reading in the positive direction on the Isothermal scale of feet, and corresponds to a change of barometric pressure from the normal of 29·99 in. to *below* normal, namely, to a reduction in atmospheric pressure.)

The dial is then rotated until the pointer stands opposite a reading of 160 ft. *above* the arbitrarily chosen mark of 1,000 ft.—namely, at 1,160 ft. (The 1,000 ft. mark is conveniently chosen instead of 0, since the scale is not always marked on the negative side of the zero.)

The instrument is then placed in the test chamber and the pressure gradually *increased*, corresponding to a "rising" barometer, until the standard mercury column reads – 1,000 ft.

If the instrument has been correctly made and adjusted, the pointer should then indicate zero, since it was previously set to compensate for the difference between the barometer reading and the standard of 29·99 in.

The pressure in the test chamber is then gradually *reduced* (at a rate equivalent to an ascent of 1,000 ft. per minute). Readings are taken at convenient multiples of 1,000 ft. up to 1,000 ft. greater than the maximum range. Down readings are then taken at the same rate and both up and down readings are tabulated.

It will probably be found that there is an error at the zero of the scale of Isothermal heights (i.e. at 29·99 in. of mercury). In this case, the readings at 0 ft. and above must be "corrected for zero error" by adding algebraically, such a figure as will reduce the error at zero to nil. Thus, if the error at zero is – 30 ft., + 30 ft. must be added to each reading.

After correcting for zero error in this way, the figures are compared with those given in the Table of Permissible Errors.

It should be noted that the true readings are all 1,000 ft. above the apparent readings, since the instrument was originally set at 1,000 ft. instead of zero, in order that negative readings might be taken. There should be no confusion, however, if the observed errors are set down in the spaces opposite the true markings.

The reader should consider carefully the reason for the "correction for zero error" referred to above. The error at zero is mainly caused by the test to – 1,000 ft., and if the instrument is allowed to rest and recover, most of this error at zero will disappear. If the error is not excessive, it may be assumed that the altimeter can safely be used starting at – 1,000 ft. (as when the barometer is "high"). Being satisfied as to this, we proceed

to consider the behaviour of the instrument when a further test is made, starting from the more usual barometric pressure, namely, 29·99 in. of mercury. In order to continue the tests without the delay involved in allowing time for the instrument to recover, the "correction for zero error" is made.

In reality, the method described above involves two separate tests: (*a*) a test on the behaviour of the instrument during a climb from ground level when the barometer is "high," namely, from the equivalent – 1,000 ft. and (*b*) a test on the behaviour of the instrument during a climb starting from ground level, when the barometer stands at 29·99 in. It is emphasized that the Table of Permissible Errors assumes the conditions of test (*b*). The correction for zero error ensures that test (*a*) shall not have any influence on test (*b*).

The use of the Isothermal and I.C.A.N. scales usually presents difficulty and is dealt with more fully in Appendix VI, p. 96.

Limitations of the Aneroid

It is desirable to emphasize the limitations of the aneroid as a height measurer.

Even if an instrument has been checked and found to be within the allowable limits of calibration, and the calibration is stable, it should be appreciated that—

1. It is calibrated for average conditions of atmospheric pressure and is subject to errors when used under any other or abnormal conditions.
2. If set for zero at sea-level before a flight it will only give reasonably accurate readings during steady flight, provided that no change in atmospheric pressure (evidenced by a change in the "height of the barometer") has taken place since the start.
3. It is subject to "cockpit error" (see p. 47).
4. During a change of height—rise or fall—it is subject to lag errors (see p. 48).
5. On landing, the height indicated will be that above sea-level and not zero—leaving the various sources of error out of account.

If these limitations are realized and allowed for when necessary, the aneroid will still prove to be a useful instrument. The advantage of an instrument giving an instantaneous reading of height above ground or sea level at any instant during a flight is obvious, but unfortunately, up to the present no such instrument has been devised. It is quite impracticable to measure the height directly and an indirect method must therefore be used. The pressure-difference method at present in use suffers from the disadvantages mentioned above. Alternative methods based on Electrical Capacity or Sound Echo principles have so far proved disappointing.

8. WATCHES [1]

For watches to be carried under the Air Navigation Directions, any make of watch of good commercial quality is accepted. The following notes are of general interest.

The driving power of a watch is derived from the mainspring which operates through a train of wheels, and is released at an even rate by the escapement, which is, as it were, the "heart" of the watch. The balance wheel and hairspring control the movements of the escapement. The

[1] For further information the reader is referred to *Modern Watch Repairing and Adjusting* (N.A.G. Press, 26 Old Street, E.C., price 4s.).

balance wheel of a watch kept continuously running vibrates about 150,000,000 times in the course of twelve months, and at the end of six months or so the oil in the movement commences to deteriorate. It is essential, therefore, for efficient running and time-keeping, that a watch should be cleaned and re-oiled at intervals of from 12 to 18 months.

The Mainspring

Breakage of the mainspring is one of the most frequent causes of failure. A broken mainspring is easily detected from the fact that the winding button turns easily and is inoperative.

The spring is a piece of tempered steel approximately 18 in. to 22 in. in length, coiled and housed in a barrel between the upper and lower plates of the movement. The strength and dimensions depend on the particular type of watch. The most common cause of breakage is over-winding, but the design is often such as to render this impossible.

The condition of the mainspring is continually varying from maximum tension when fully wound to minimum tension when the watch has run down. It is also subject to extreme changes of temperature, ageing, and deterioration. These conditions are outside the control of the user and occasionally result in failure.

The Balance Staff

The balance staff is the shaft on which the balance wheel rotates. It is provided at each end with a very fine pivot in order to reduce friction to a minimum. The pivots rotate in jewelled holes, and, being delicate, will bend or break with the greatest ease if the watch is subjected to rough treatment. A breakage will result in the balance wheel stopping. A bent pivot causes unevenness of motion to be imparted to the balance wheel, resulting in bad time-keeping or intermittent running.

Jewels

In every well-constructed watch of the lever escapement type there should be at least seven jewels. The balance wheel unit should have two jewels at each end—a jewel-hole and an end-jewel. Periodically the balance wheel staff is in contact with a fork piece with two branches at the other end. These are known as pallets, and they permit the release of the escape wheel alternately. Each pallet has a jewel. The seventh jewel is in the balance and engages with the fork. In a fifteen-jewel movement, eight more jewels are provided for the pivots of the pallet staff, the escape wheel, and the third and fourth wheels.

Trouble may be caused by badly fitting or cracked jewels, the refitting of which calls for considerable skill and experience and should only be undertaken by an experienced watchmaker.

Balance and Hairspring

The balance and hairspring are very important parts of a watch, and it is chiefly these parts which distinguish a good watch from an inferior one. In almost all watches, except those of low grade, the balance wheel consists of bimetallic segments of brass and steel, constituting the rim. A number of small screws (in the rim) weight and poise the balance according to the strength of the hairspring. The rating adjustments are made in the balance wheel and hairspring. The performance is usually expressed as a "rate," and a watch may have a gaining rate or a losing rate. The balance wheel controls the action of the escapement and oscillates about

three-quarters of a revolution in each direction. The wheel needs control and this is the function of the hairspring. Hairsprings are usually either of the flat or of the Breguet (or overcoil) type. The former is a simple flat coil spring. In the latter type (named after Breguet, an early watchmaker who first applied the principle) the outer coil is diverted from the true spiral, and the end is brought over the inner coils to its anchorage. This design is an attempt to allow free expansion and contraction of the spring in all directions, and reduces unevenness and side-friction on the pivots, and obviates the effect of position errors on an unbalanced hairspring.

Watches should be adjusted for time-keeping under conditions of temperature and position. Temperature adjustments are made in the

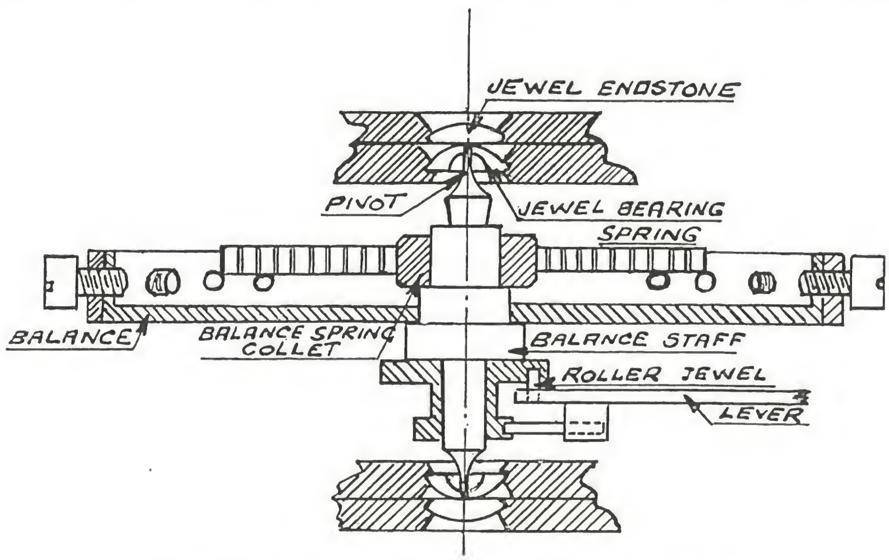


FIG. 38. SECTIONAL DIAGRAM OF WATCH BALANCE

balance wheel. Position adjustments are effected by the correct adjustment of the whole balance assembly—hairspring and escapement.

Magnetism

Occasionally, erratic time-keeping can be traced to the hairspring having become magnetized. It can be cured by suspending the watch by a twisted cord near a powerful magnet, and allowing the cord to unwind and rotate the watch, which is gradually withdrawn from the neighbourhood of the magnet while still rotating.

The Hands

Unless the hands of a watch are carefully fitted, they may touch one another or the dial or glass during their revolutions and cause the watch to stop. "Unbreakable glasses" of a celluloid compound are now often fitted and, being relatively soft, may be pressed down in contact with the hands and bend them out of position. It is advisable, therefore, to test by drawing the winding stem into the "set hands" position and carefully rotate the hands, while watching closely the clearance between the dial, the glass, and the hands. Adjustments can be made with a pair of tweezers.

Timing

The 30-hour watch should not gain or lose more than 30 sec. in a 24-hours' run. Tests should be made in three consecutive days in the position in which the pendant is uppermost. The balance poise can be checked by timing when the pendant is 30 degrees on either side of the vertical.

9. TURN INDICATORS AND BANK INDICATORS

The turn indicator is used primarily for indicating deviations from a straight horizontal course. When flying in cloud or fog, in the absence of some external point of reference, and when there is no visible horizon to

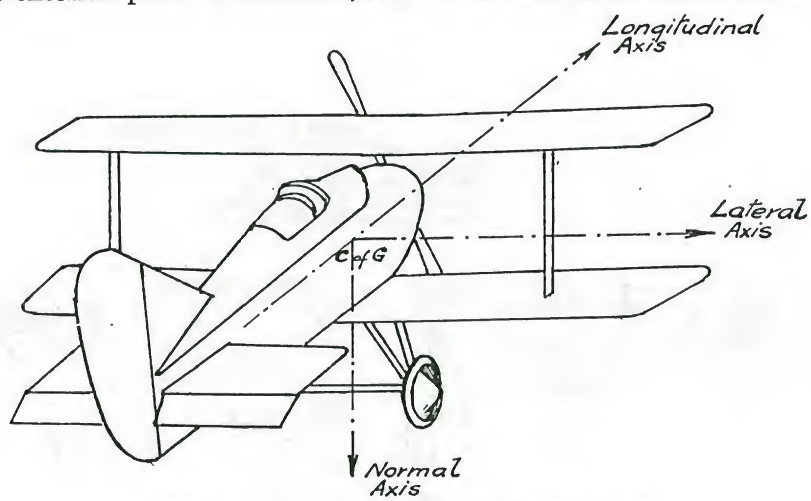


FIG. 39. THE AXES OF THE AEROPLANE

act as a guide, it is practically impossible for the pilot to keep the machine on a straight course. Without realizing it, the pilot may be flying in a sharp curve, and it has even happened that, on emerging from a cloud, the pilot has found that he was flying upside down.

If the angle of bank is large, the pilot may realize from his muscular reactions that he is not on a straight course, but he cannot tell whether he is in a right-hand or a left-hand turn. If he attempts to straighten his course, he is quite likely to make incorrect movements of the controls and increase the curvature instead of reducing it. The compass is no guide to him in these conditions as the readings are unreliable when the speed of the aeroplane is changing or during a turning movement (see p. 68).

An essential requirement is therefore a turn indicator—an instrument which indicates, under all conditions, whether the path of the aeroplane is a straight line or whether it is turning to right or to left. The instrument not only enables the pilot to keep a straight course but, at the same time, affords valuable information of the rate of turn either to right or left, as well as of the correctness of his banking. The general effect on the machine of incorrect banking has already been considered in the section on cross-levels.

The Axes of an Aeroplane

The movements of an aeroplane in normal flight are usually referred to a system of three mutually perpendicular axes, fixed in the aircraft and moving with it.

These axes all pass through the centre of gravity and their positions will be clear from the diagram.

The following table shows the effect of a turn about each axis, names the control producing the turn, and mentions one instrument in each case which may serve to indicate the turn.

Axis of turn	Control	Movement	Indicating Instrument
Longitudinal	Ailerons	Roll or bank	Cross Level
Lateral	Elevator	Pitch	Fore and Aft Level
Normal	Rudder	Yaw	Compass

Most of the types of turn indicator in general use are proprietary, and the makers give full instructions for installing and maintaining their instruments in proper working condition. These instructions should be carefully studied, as successful performance depends very largely on closely following them. If a fault develops it is seldom possible to correct it, and, therefore, in this case, the wise course is to return the instrument to the makers for overhaul and adjustment.

Several types have been approved for use in civil aircraft. The minimum requirements are laid down in Civil Instrument Specification No. 8 (see p. 130). See also Civil Specification No. 14 (Directional Gyro).

The Venturi Tube

Many Turn Indicators are operated by the suction produced by a Venturi tube, acting on the same principle as the injector on steam engines.

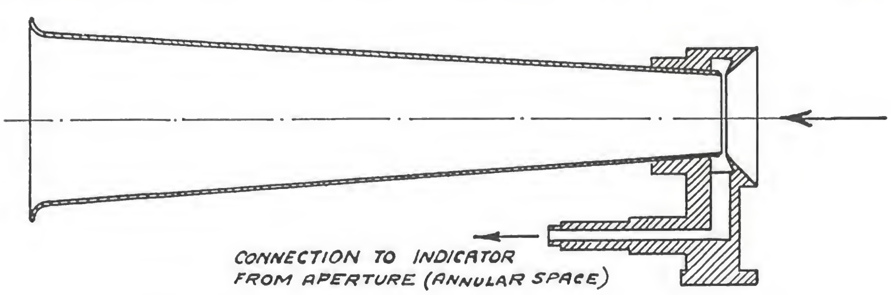


FIG. 40. DIAGRAM OF VENTURI TUBE (REID-SIGRIST)

The Venturi is a tapered tube open at both ends, placed in an air stream. The flow of air through the tube causes a reduction of pressure at a side aperture which is connected by tubing to the airtight case of the indicator. The suction created by the reduced pressure causes air to be drawn from the exterior of the indicator case through a jet, which impinges on the grooved periphery of the rotating wheel constituting the gyro. In this way the rotation of the wheel is maintained.

The advantage of fitting the Venturi in the slip stream is that the instrument is caused to operate from the moment the airscrew is set in motion. Thus, indications are given from the start of a flight—an important consideration in foggy weather.

Turn indicators driven by Venturis can be simply constructed and made

mechanically reliable. Owing to the exposed position of the Venturi and the cooling effect of the air flow, there is liability of blockage due to the formation of snow and ice at low temperatures. To avoid this trouble in some American types, the Venturis are electrically heated.

Electrically driven turn indicators are not subject to these troubles and can be conveniently designed to give indications by illuminated coloured screens. As the instrument serves as an auxiliary to the compass, it is usual to group the two instruments near to one another, and therefore freedom from interference with the compass is an important feature of the design which must be carefully considered. Regular maintenance also is important to ensure satisfactory service.

The Reid Control Indicator

The Reid Control Indicator combines three functions in one instrument, giving indications of the movement of the machine in three directions. An air speed indicator is fitted centrally, giving readings of movement in the fore-and-aft direction. If the nose of the machine moves downward, an increase of speed will be indicated. If the nose moves upward, the pointer will show a corresponding decrease of speed.

Indications of turn to right and left, and of tilt in a transverse direction, are given by systems of small electric lamps. If the aircraft turns about its longitudinal axis, mercury in a U-shaped glass tube, mounted parallel to the front of the instrument case, moves under gravity and makes electrical contacts (by wires fused into the glass), causing one or more of the series of "aileron" lamps to light up. The lamps are arranged round the upper half of the air speed indicator case, and, by observing them, the pilot knows how to use his aileron control in order to correct the displacement and restore the machine to normal flying position. The arrangement acts as a bubble level. A lower row of horizontal lights (controlled by a small gyro, with its axis set in the horizontal plane of the aircraft) gives indications for rudder control. The gyro rotates at about 5,000 r.p.m., and is actuated by a small Venturi. Its movements, relative to the frame, cause electrical contacts to be made by insulated flat springs in circuit with the series of lamps. The pilot manipulates the rudder control so as to keep the centre lamp only illuminated.

Care should be taken in installing the instrument, and the detailed instructions for fitting should be carefully followed. The indicator must be squarely fitted when the aircraft is trimmed on a level keel. The best method is to tilt the instrument case first to one side, then to the other, and to mark the position when the first lamp in each case lights up. The half-way position is correct.

The gyro unit is fixed by means of a split clamp ring and must be fitted so that the axis of the gyro is in the horizontal plane. The control taps should be placed within easy reach of the pilot. It is best to fit the Venturi in the slip-stream of the propeller, where there is a good unobstructed flow of air.

The following types of Turn Indicator incorporate a gyroscope. The reader is referred to Appendix VII (p. 101) for further details.

The Pioneer Turn Indicator

The Pioneer type of turn indicator utilizes a small air-driven gyroscope operated by a Venturi. The indicator is mounted on the instrument panel with the dial vertical, so that the ball is in the centre of the cross-level tube (incorporated in the dial) when the aircraft is in normal flying attitude. Connexion to the Venturi is made by a suitable

length of $\frac{1}{4}$-in. copper or brass tube, which should have as few bends as possible. The cones of the connecting unions should be soldered to the tube, care being taken to avoid any of the solder running on to the cone seating. Coupling nuts are provided for tightening up the joints. The Venturi should be mounted with the "arrow" pointing forward, on the side of the fuselage or on a strut, preferably in the slip-stream so as to receive an unobstructed current of air.

The Venturi must be examined periodically for freedom from obstruction or dirt, and the nuts tested occasionally for tightness. At the back of the instrument there is a jet screen, which can be removed by unscrewing the knurled retaining nut. The screen should be cleaned after 100 hours' flying time. The only place where oiling is necessary is the screw hole on the right-hand side of the instrument case. Six drops of oil of good quality should be used for the purpose after every 300 hours' flying.

The Schilovsky-Cooke Turn Indicator

The Schilovsky-Cooke Turn Indicator employs a slow-speed, direct-current electric motor, acting as a gyro. The motor is mounted with its axis athwart the aircraft, and the axle is carried in a gimbal ring pivoted at its front and rear ends on knife edges. It is also weighted so that the axis of the gyro is horizontal when the gyro is not rotating. The gyro is run from a 12-volt battery, and turns at a rate of about 1,200 r.p.m. The axis of the gyro in motion tends to preservė its direction in space. When the aircraft turns, a transparent coloured screen attached to the gimbal ring moves across a window at the top of the instrument case, giving indications of the direction and the amount of the turn by exposing green or red bands of light from a small lamp at the back. The gyro element on its knife-edge bearings constitutes a long period compound pendulum with slight gravitational control. On switching on the current by the lever provided, the gimbal frame is deflected momentarily so that it swings freely and comes to rest in the correct position. On switching off, the whole gimbal frame assembly is automatically clamped to prevent damage by vibration. The instrument embodies a mechanical pendulum, which serves as a cross-level device, giving indications by means of the movements of a "bubble," illuminated so as to appear as a bubble of white light.

Tests on the sensitivity of the instrument are made on a turntable, which can be caused to rotate at constant measured speeds. The instrument should show the same deflections on each side of the vertical for each speed for either direction of rotation. The following is the usual scale of sensitivity—

1 turn per 15 min.	. .	Deflection	not	less	than	5°
1 ,, $7\frac{3}{4}$,,	. .	,,	,,	more	,,	10°
1 ,, $7\frac{1}{4}$,,	. .	,,	,,	less	,,	10°
1 ,, 4 ,,	. .	,,	,,	less	,,	$17\frac{1}{2}$°

A scale of spots corresponding to the above deflections is provided just above the window, for convenience during the test.

Both the gyro movement and the cross-level are provided with independent air dash-pots to reduce the oscillation of the mechanism. Control of the "damping" is effected by manipulating knurled knobs at the bottom of the instrument case. The final adjustments to suit the particular aircraft are made in the air during a trial flight. The damping adjustment does not affect the sensitivity, but is necessary in order to avoid undue lag or too rapid movement of the coloured screens. A given

rate of turn will always produce the same deflection, either quickly or slowly, according to the adjustment of the damping. The illumination is controlled by a dimming switch which limits the amount of current passing to a value between 0·6 and 0·8 amp.

The installation must be carefully carried out. The instrument must be mounted on the instrument panel in full view of the pilot and as far from the compass as possible, owing to the mass of iron used in the construction. The minimum permissible distance is 4 in. between the edges of the two instruments.

The compass may show a momentary deflection at the moment the switch is operated either to the "on" or "off" position, but the permanent effect is negligible. Adjustment of the compass must be made after the turn indicator has been fitted. The indicator is fitted by spring bolts provided with nuts and washers, and the upper part is retained in position by a spring clip which permits of the instrument being tilted forward through a small angle—sufficiently far to enable the cover of the lamp recess at the back to be removed and the lamp changed, should this be necessary. The retaining clip must therefore be mounted a little to the left or right of the vertical central line to enable this to be achieved.

The student will find it to his advantage to consider the various positions of the pointer and the bubble under different conditions of flight. Reference should be made to the section on cross-levels, where the causes of the movements of the bubble are discussed.

The Reid-Sigrist Turn Indicator

The Reid-Sigrist Turn Indicator embodies a gyroscope, driven by a Venturi, and a cross-level indicating device. The gyro is mounted in an horizontal gimbal ring of which the axis is in a fore-and-aft direction, the gyro axis being in a transverse direction. Any tendency of the aircraft to turn off its course applies a torque to the gyro. This torque produces precessional motion causing the gimbal ring to rotate about its fore and aft axis. If this movement were uncontrolled the gimbal ring would continue to rotate until it had moved through 90°. It is, however, controlled by a spring, the tension in which balances the precessional torque. A toothed quadrant fixed to the gimbal ring operates a simple damping mechanism, consisting of a small piston driven by a geared-up crank and working in a cylinder. The movements of the gimbal are communicated to the pointer by a two-to-one magnifying mechanism. The sensitivity of the instrument is controlled by a spiral spring, the tension in which can be adjusted by a screw, accessible through a hole in the case; the hole is normally closed by a screwed plug.

The instrument indicates the *rate of turn*, namely, the ratio between the number of degrees turned through, and the time taken. Thus, there is a quick response at the commencement of the turn, and the pilot can immediately make the necessary corrective movements of the control before the movement becomes excessive. The indications of the "rate of turn" pointer are not affected by the attitude of the aircraft, and are the same if the machine is flying upside-down. The pointer moves always in the direction to which the nose of the aircraft is moving, and the angle it assumes shows the rate of turn (or yaw) of the machine.

The cross-level indicator takes the form of a pendulum fitted in a little box of triangular section placed just behind the dial. The clearance between the plate pendulum and the sides of the box is very small, and provides suitable damping. The movements of the pendulum are communicated to the pointer (working over the upper part of the dial) by

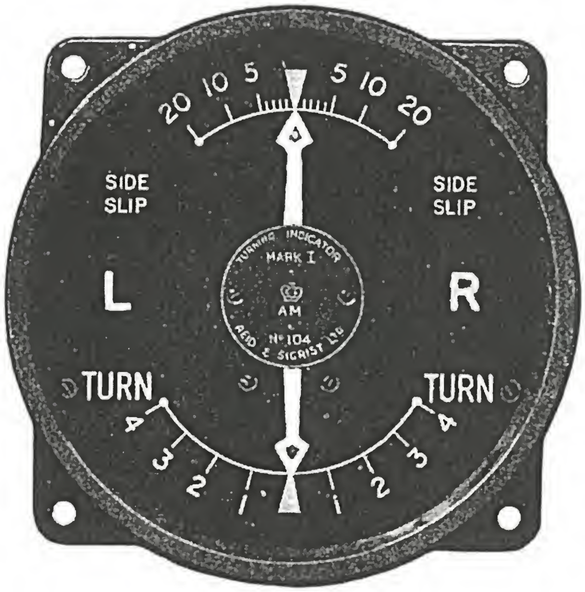


FIG. 41. "REID-SIGRIST" TURN INDICATOR

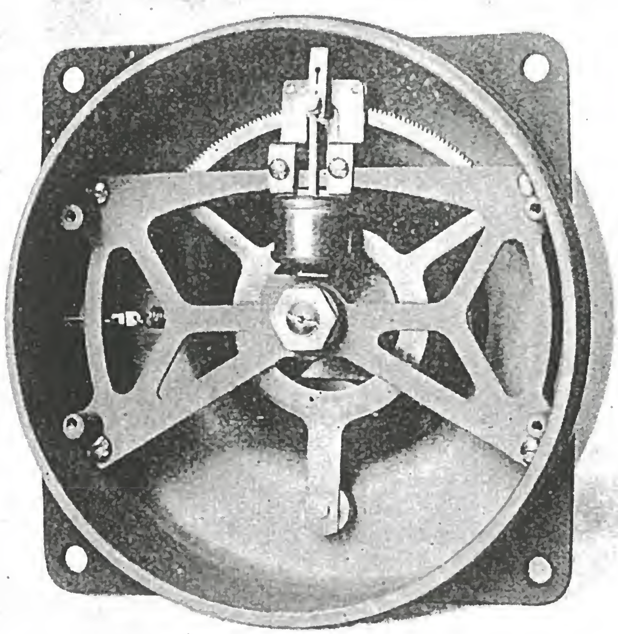
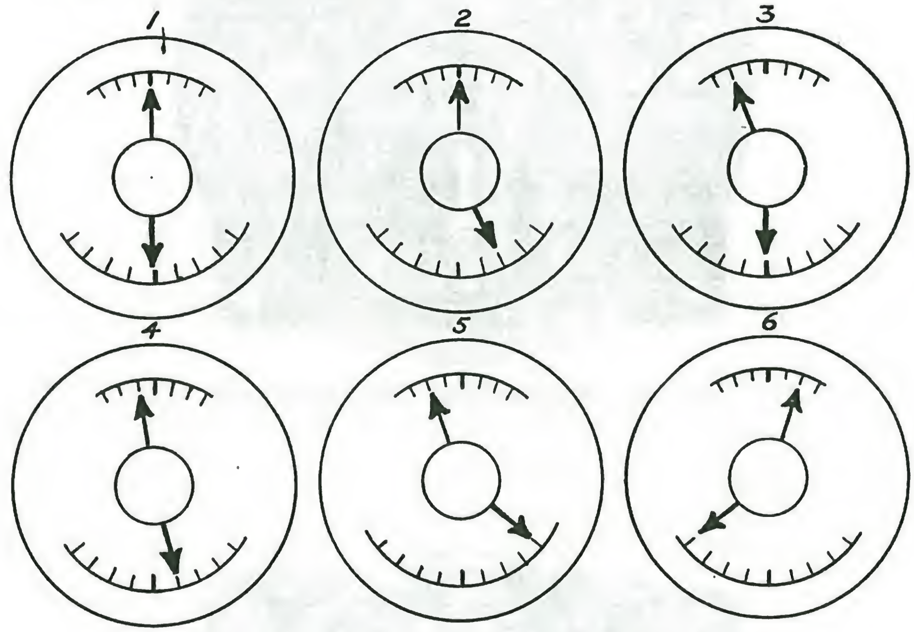


FIG. 42. "REID-SIGRIST" TURN INDICATOR. (INTERIOR VIEW SHOWING DAMPING MECHANISM AND SENSITIVITY CONTROL SPRING)

mechanism which gives large indications for small angles of tilt—the magnification is approximately 5 to 1 at the zero, which makes it possible to fly within ½ degree of lateral level.

The examples of instrument indication illustrated should be studied—

1. Straight flight.
2. Turn to right. Banking correct.
3. No turn. Side-slip to left.



REID-SIGRIST TURN INDICATOR
EXAMPLES OF INSTRUMENT INDICATIONS

FIG. 43

4. Turn to right. Slight side-slip to left.
5. Spin to right.
6. Spin to left.

Tests

The instrument is tested with the dial in a vertical plane, and with an air suction equivalent to 3 in. of mercury. The gyro must commence to rotate with a reduction in pressure of ¼ in. of mercury, and, after it has attained full running speed, must continue to rotate for at least 18 min. after the suction has been shut off. The sensitivity must be within the limits quoted in the relative specification, when tested in the usual manner on a smoothly turning turntable, of which the speed can be varied. Light tapping of the instrument is permissible during test, to overcome friction at the pivot which would normally be overcome by the vibration of the instrument panel during flight. The damping of the turn unit and pendulum unit must be such that after a given displacement the pointer shall not overshoot the zero, on its return, by more than half a division. The range of the pendulum unit is 20° either side of zero, and the errors must not exceed plus or minus 0·5° at the zero, and plus or minus 2·0° at any other part of the scale. To test for freedom of the pendulum, the

instrument should be placed with the dial at 75° from the vertical both backwards and forwards and swung slowly from side to side.

Installation and Maintenance

The indicator is fitted to the instrument panel, so that the cross-level pointer is central when the aircraft is in normal flying attitude. The Venturi is fitted with its axis horizontal and the bracket end facing forward in the slip-stream, where the air current is unobstructed and free

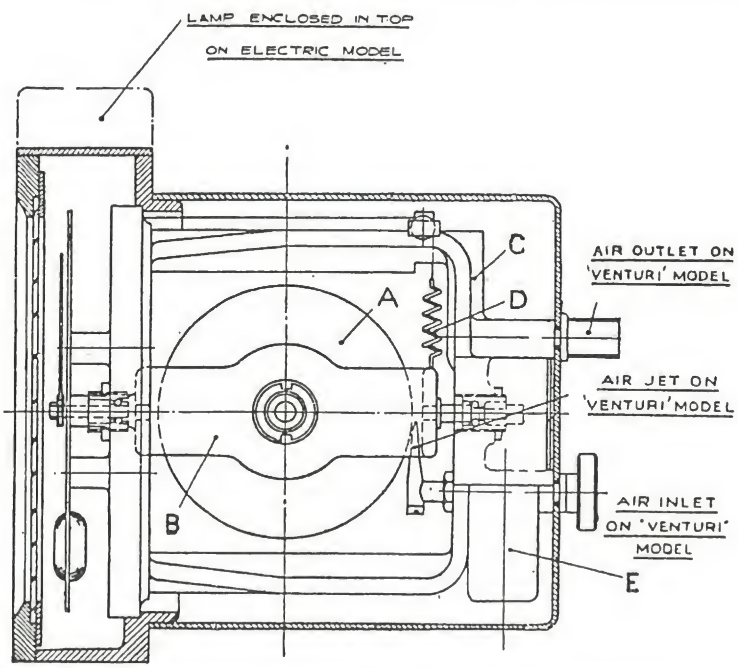


FIG. 44. MECHANISM OF "BROWN" TURN INDICATOR

A. Wheel
B. Inner frame
C. Outer frame
D. Control spring
E. Dashpot

from oil mist; a good position can usually be found on the centre section strut. Nipple connections are provided on the indicator and Venturi for connecting up with the pipe-line by means of low pressure unions. Occasionally, say after every 300 hours' flying, the inside of the Venturi should be cleaned and the neck examined to see that there are no accumulations of dust or dirt. The connexions should be tested for airtightness, and the bezel of the instrument case screwed home so that no leaks occur. Occasionally the pipe lines should be disconnected and a stream of air from a pump passed through them to ensure freedom from obstruction or moisture. The filter over the air jet of the instrument should be removed and the gauze cleaned. It is readily accessible if the three small screws securing the filter cap are removed.

The "S. G. Brown" Venturi (Type A) Turn Indicator

The "S. G. Brown" Venturi (Type A) Turn Indicator consists essentially of a small wheel revolving at 3,500 r.p.m. The axis of the wheel is set horizontally and is mounted in a small frame, which in turn is mounted

in an outer frame fixed to the body of the instrument. The outer frame carries a graduated card on its forward end. The spindle of the front bearing frame is extended through this card and attached to a pointer, which moves over a graduated scale as the wheel and its frame are tilted from the horizontal. In plan view the pointer is in the shape of a small aeroplane. A pipe is led in from the back of the outer case through the outer frame, and terminates in an air jet which impinges in serrations or cups mounted in the periphery of the wheel. The outer end of the pipe is fitted with a fine gauze-covered screw cap, which prevents the ingress of dust. The inner frame carries two pistons operating in cylinders to provide suitable dashpot damping.

FIG. 45. "BROWN" (TYPE E) TURN INDICATOR

A small spring (of which the tension can be varied by the manipulating of a small knob on the front of the case) controls the horizontal position of the inner frame. The sensitivity is adjustable to any of the five positions of the switch in the top right-hand corner of the instrument case. An on-and-off switch in the top left-hand corner serves to put the instrument in or out of action as required.

An inclinometer is incorporated in the instrument, and consists of a pendulous damped pointer operating over a scale marked at each 10 degrees of tilt.

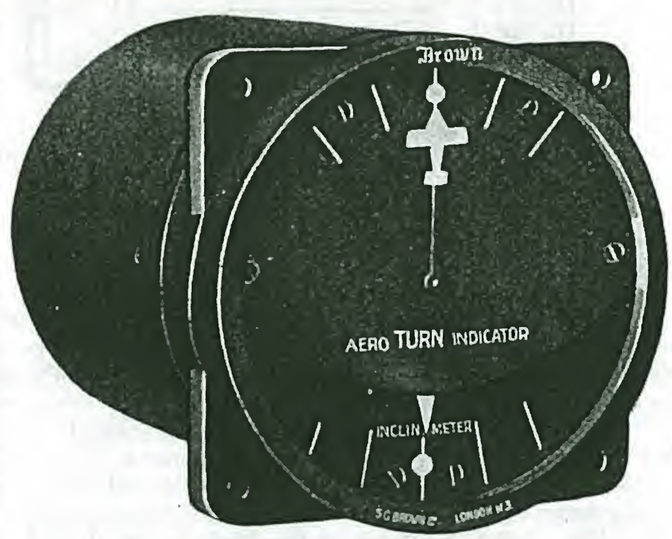


FIG. 46. "BROWN" VENTURI MODEL TURN INDICATOR (NEW TYPE)

On the glass inside the instrument is painted a fixed datum line in the form of a small aeroplane. If the machine banks, left wing low, the pointer will keep still vertical, but the small aeroplane will appear to be left wing down. All that is necessary to bring the aircraft level is to follow the apparent motion of the indicator to the right with the control column. When the aircraft is correctly banked during a turn, the pointer remains in the centre of the scale.

The "S. G. Brown" (Type E) Turn Indicator

The "S. G. Brown" (Type E) Turn Indicator is an instrument of similar construction to the Venturi type, but is driven electrically from a 12-volt battery, the working current being $\frac{1}{2}$ amp. It is internally illuminated and, as the pointer moves to left or right during a turn, red or green windows are uncovered. A dimming switch controls the amount of illumination.

The New "Brown" Venturi Model Turn Indicator

A new "Brown" Venturi Model Turn Indicator has been produced quite recently by Messrs. S. G. Brown. In this instrument, great attention has been paid to the damping of the gyroscopic element, and a very exact zero is obtained on the turn indicator. The sensitivity adjustment and the on-and-off control have been eliminated, thus simplifying the instrument, which is more robust than the earlier types and occupies less room on the instrument panel. A very important point is that the inclinometer pointer gives reverse readings to the older types.

Fig. 47. Turn and Bank Indicator
(Henry Hughes and Son)

The "Hughes" Turn and Bank Indicator

The "Hughes" Turn Indicator embodies a gyroscope wheel mounted in a gimbal ring pivoted fore-and-aft of the instrument case, the pivots being rigidly attached to the case. The gyroscope wheel is air-driven by means of a Venturi tube which creates partial vacuum inside the case. The air is sucked in through a nozzle and then impinges on peripheral slots cut in the wheel.

Movement of the case in azimuth gives rise to a precessional movement of the wheel, which in turn actuates the indicating pointer. A suitable return spring is incorporated, the tension of which determines the sensitivity of the instrument. Oscillation of the moving parts is controlled by air-damped pistons.

The Bank Indicator consists of a steel ball free to move in a radial glass tube, and suitably damped by means of a non-freezing liquid.

The Sperry Horizon and Directional Gyro have been designed to give direct and immediate indications of the movement of an aircraft in three directions—

The Sperry Horizon provides a visual picture of the attitude of the aircraft (represented by a miniature aeroplane on the dial) relative to an "artificial horizon" bar moving across the dial of the instrument.

The graduations show *the actual degree of bank* during a turn. The pitch, when climbing or gliding, is indicated by the position of the miniature aeroplane above or below the horizon bar.

The gyro is maintained in rotation by air suction from a Venturi or

air pump, and is mounted so as to spin in a horizontal plane about a vertical axis.

Four horizontal jets connect to equally spaced openings at the bottom of the gyro case. Over these openings hang vanes, so disposed that when the gyro axis is vertical, half of each opening is covered by its vane. If the gyro axis inclines away from the vertical, one vane covers more than half (and the vane on the opposite side covers less than half) of its respective

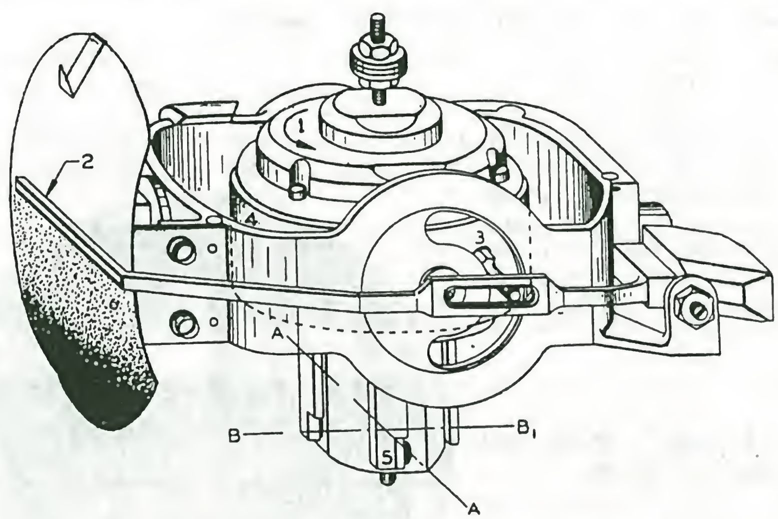


FIG. 48. DIAGRAM OF "SPERRY" HORIZON

(Sperry Gyroscope Co.)

1. Gyro axle
2. Horizon bar
3. Actuating pin
4. Gyro case
5. Hanging vane

opening. Consequently the air stream through the jet is increased on the side on which the opening is greater and the added reaction on the casing causes the gyro to "precess," i.e. to tilt in a direction at right angles to the applied force.

The restoring action of the precessional forces is arranged so that the axis of the gyro is never allowed to incline more than two degrees from the true vertical. The horizon bar is actuated by a pin protruding from the gyro case through a slot in the gimbal ring. For all practical purposes, the horizon bar acts as an artificial horizon, when the natural horizon is not visible.

The Sperry Directional Gyro is also actuated by air suction from a Venturi or air pump.

A circular Compass Card graduated in degrees is attached to the vertical ring on which the rotor and its gimbal ring are mounted. The vertical ring and card turn freely in azimuth in the vertical bearings and a portion of the card is visible through a small window in the front of the instrument case.

When the gyro is rotating, its axis and supporting ring as well as the Compass Card remain fixed in azimuth and thus any rotation of the aircraft will be indicated by a movement of the card relative to the datum mark across the window. The gyro is subject to slight drift (approximately 2° per 15 to 20 minutes) and therefore needs resetting, from time to time,

by pressing and turning the knob below the dial until the reading agrees with that of the Magnetic Compass.

It should be noted that these instruments show the actual number of degrees turned through and not the *rates* of turn as in some types of turn indicator.

Unlike bubble types of spirit levels and pendulum devices, they are

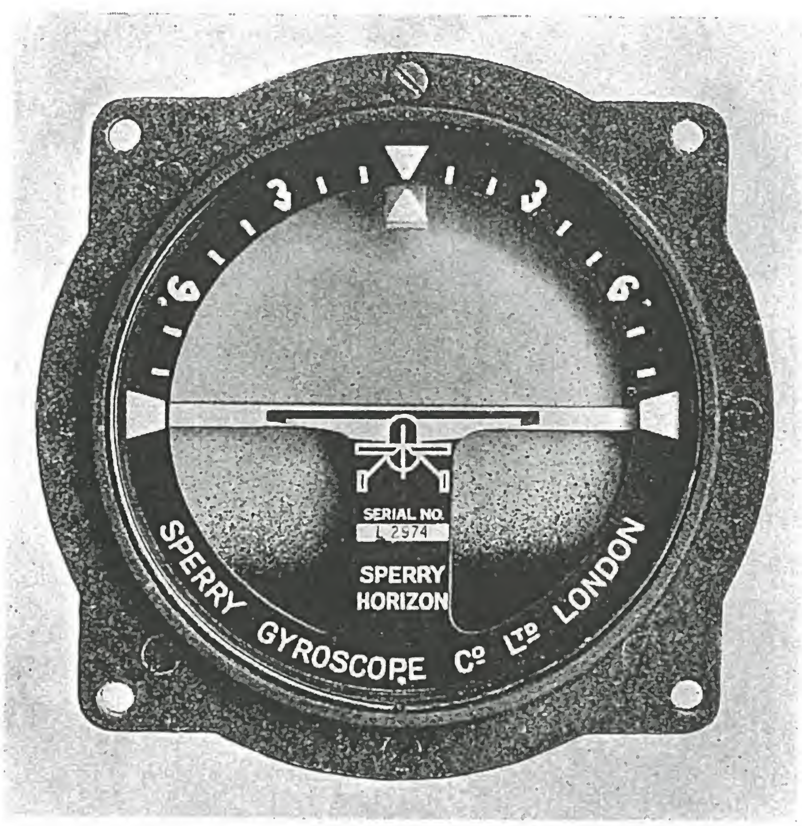


FIG. 49. "SPERRY" HORIZON
(*Sperry Gyroscope Co.*)

not subject to acceleration forces due to turning or changes in speed. The instruments are designed to give the pilot direct information as to how far he may have steered from a given course and how far he must turn to proceed on a new course.

10. COMPASSES

The Aircraft Compass has to be specially designed to meet the particular conditions in which it is used in the air. When the speed of the aircraft is changing, or when the aircraft is executing a turning movement, the readings of an ordinary compass are unreliable.

The reasons for the inaccuracies introduced may be appreciated by considering the forces on a simple magnetized needle freely suspended at its centre of gravity. The magnetic axis tends to set itself in the magnetic meridian under the action of the earth's magnetism, and the resultant

Climb—level laterally

30° Right Bank | Level Flight | 30° Left Bank

Dive—level laterally

FIG. 50. INDICATIONS OF "SPERRY" HORIZON

(Sperry Gyroscope Co.)

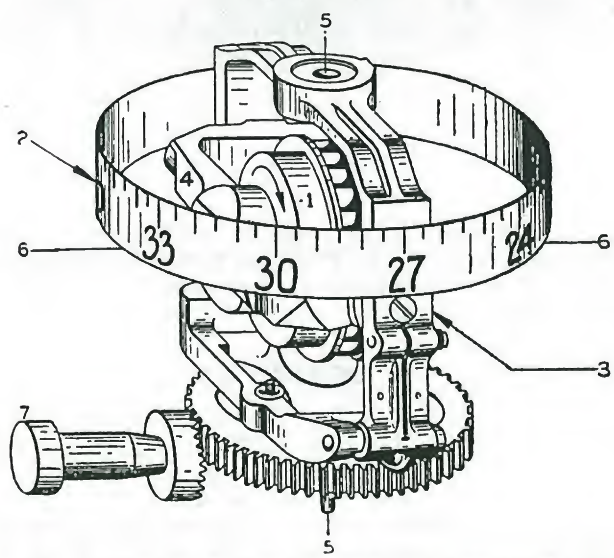


FIG. 51. DIAGRAM OF THE "SPERRY" DIRECTIONAL GYRO

1. Gyro wheel
2. Compass card
3. Vertical supporting ring
4. Gimbal ring
5. Bearings
6. Gyro axle
7. Setting knob

force may be resolved into horizontal and vertical components, which may be considered separately. The vertical component causes the needle to dip slightly. The horizontal component causes the needle to point to the magnetic North. Its value is very small—about ·185 dyne (= 1/30,000 oz. wt.).

In an aircraft compass, the magnet system consists of a number of magnetized needles arranged parallel to one another in such a way that

FIG. 52. "SPERRY" DIRECTIONAL GYRO
(Sperry Gyroscope Co.)

the inertia is small in comparison with the magnetic moment, and the system is balanced both statically and dynamically. The directional error should not be greater than 1°. The centre of gravity of the pivoted system is kept well below the point of support, so as to make the angle of dip due to the vertical component of the earth's magnetic force as small as possible. Except on the equator, the magnet system will dip[1]—with the north-seeking end (marked "N") downwards in the northern hemisphere, and with the south-seeking end (marked "S") downwards in the southern hemisphere. In the former case, the centre of gravity will be displaced to the south if the aircraft is flying eastwards. If the aircraft suddenly in-

[1] The magnet system should be constructed so that its dip will not exceed 3° anywhere between the latitudes 60° N. and 60° S. In England, it should be north end down by an angle not exceeding 2°.

creases speed, acceleration forces acting at the centre of gravity will produce a deviation in a clockwise direction. On the other hand, a decrease in speed will produce anti-clockwise deviations. The error introduced is called the **Speed Error,** and is most serious when the speed is suddenly changed on east and west courses.

When the aircraft turns, centrifugal forces acting at the centre of gravity produce what is called the **Northerly Turning Error.** Suppose the aircraft makes a banked turn when heading magnetic north. The N. end of the magnet system moves downwards, and the compass card will move in the same direction as the aircraft. It may even turn faster than the aircraft and produce the effect of a turn in the opposite direction. In the early days of flying the northern turning error was not understood, and a pilot's attempt to counteract the apparent turn in the other direction often resulted in a spin. Double pivoted compasses (in which the compass card is horizontal when the pivots are in a vertical line) have been introduced; they are unaffected by turning error when making a flat (unbanked) turn.

In order to minimize oscillations, the magnet system must be designed so as to be as dead-beat as possible, that is, if the magnet system be displaced from the meridian, it must return to the equilibrium position in the minimum time. This condition is secured by devices such as damping filaments, the movements of which through the liquid do not cause movement of the liquid as a whole, but merely set up eddies which are quickly dissipated. Compasses in which the magnet system after deflection returns to the equilibrium position directly without oscillating are said to be **Aperiodic.** Pivot friction is reduced to a minimum by the use of agate or iridium pivots in sapphire bearing-cups, so that the relatively weak forces due to the earth's magnetism may give a clear indication on the compass card. A tilting freedom of 15° is usually allowed in all aircraft compasses—that is to say, the magnet system must be free to move if the bowl is tilted to any angle not exceeding 15°.

The use of liquid in the compass bowl assists in damping out oscillations and vibrations and also serves partially to support the magnet system, and enable it to respond more freely to movements of the aircraft. Usually a solution of alcohol is used on account of its low freezing-point[1] and small coefficient of expansion. The compass should withstand a wide range of temperature ($-25°$ to $+50°$) without derangement. Over the range named, the change in volume of a 90 per cent solution of alcohol in water is approximately 12 per cent, and an expansion chamber is usually incorporated to allow for this. A further reason for the use of alcohol in compasses is its low viscosity. If the compass bowl is turned in azimuth, the liquid tends to be dragged round with the bowl and eddies are set up at the circumference. These penetrate towards the centre and set up rotation in the magnet system. This effect is known as "liquid swirl," and is minimized by the use of liquid of small viscosity.

Alcohol acts on most paints, many metals, and on sulphur (often used in the rubber jointing washers), and causes the liquid to become discoloured in course of time. Special paints are employed, or the interior of the compass bowl is often coated with vitreous enamel in order to avoid this trouble.

Various shock-absorbing devices have been adopted in order to minimize the effect of vibration.

[1] Whatever the composition of the liquid, the freezing point should be below $-35°$ C.

This survey of some of the principal problems involved in the construction of aircraft compasses will enable the student to appreciate more fully the following notes on approved types, and the hints for installation, maintenance, and adjustment.

Approved Types of Compasses

Several types of Compass have been approved for use on civil aircraft. Specification No. 9 (see p. 132) lays down the minimum requirements.

Type 6/18.

The type 6/18 Compass is aperiodic (see p. 68). The magnet system carries eight radial damping wires, spaced at 45°, four of which are marked N., E., S., and W. respectively. A rotatable grid ring is fitted above the bowl, and can be locked in any desired position by two locking levers. The ring is graduated every 2°. Four parallel wires (the grid wires) are fitted across the grid ring. The lubber line is marked inside the bowl, and is visible at the edge of the glass. In determining a course, the grid ring is turned until the grid wires are parallel to the N.–S. wires of the moving magnetic system, and the N. wire registers with the N. mark on the ring. The ring is then clamped, and the course is indicated by the mark of the scale which registers with the lubber line.

Type P2.

The P2 Compass is a modified form of type 6/18. The bowl is enclosed in a cylindrical container, and its interior is coated with a vitreous enamel which is not so likely to be affected by alcohol as paint. The grid ring can be removed by unclamping and setting the N. mark against the lubber line. On raising the N. side of the ring it can be lifted off to allow the glass front of the compass bowl to be cleaned without risk of damage to the grid wires.

Type P3.

Type P3 Compass was designed for use in aircraft where (for reasons of restrictions of space) it is necessary to fit the compass at or about the level of the pilot's eye. Through the vertical verge glass, the compass card with graduations marked on its rim can be seen against the black painted background of the interior of the spherical compass bowl. This arrangement gives the maximum range of vision in the vertical plane. The magnet system, damped by four glass damping filaments, carries the cylindrical compass card, marked every 5°. On the verge glass a luminous lubber line is painted. The cardinal points (N., S., E., and W.) and the quadrantal marks (N.E., S.E., S.W., and N.W.) are also luminized, and a small electric lamp is fitted at the top of the verge ring. The corrector box, fitted below the bowl, is detachable, and contains a number of small bar magnets used in correcting for deviation as explained later. The anti-vibrational devices are of the floating ring and sorbo-sponge bracket type.

Type P4.

Type P4 Compass is intended for fitting below eye-level for observation from above. Eight radial damping filaments equally spaced are carried by the magnet system, and are arranged so that the wires marked N. and S. are parallel to the compass needles. The grid ring, fitted above

the bowl, can be rotated and locked in any desired position by a clamping device. Its inner circumference is graduated every 2°, and carries four wires (the grid wires) which can be set, parallel in pairs, to the damping filaments marked N.S. and E.W. The course is then read off against the lubber line which is marked on the inside of the bowl. The N.S. and E.W. cross-filaments and the lubber line are made in the form of sealed glass capillary tubes to obviate any action of the alcohol on the luminous compound. The grid ring may be removed for the purpose of cleaning and lubricating the under rim, by unscrewing the three countersunk brass screws by which it is attached to the top of the bowl.

Type O2.

The type O2 Compass was designed for use by the observer or navigator, and can be mounted on suitable mountings in various parts of the aircraft, so that bearings can be taken either to left or right of the flying axis. The magnet system is heavily damped, and carries a small mica card (graduated to 2°) with letters and numbers reversed so that they appear in normal position when read through a magnifying prism mounted on the verge ring, which can be rotated and locked in position as desired. A sighting device consisting of a reflector and two coloured glasses can be adjusted by a knurled screw. The fixed lubber line enables the course to be read through the prism; thus the compass can be used to steer a course, or to keep a given course.

Standard fittings are provided for housing the compass either on the left or right side of the aircraft, and these are suitably marked to ensure that the compass is inserted in the correct position.

Type O2T.

The O2T Compass is arranged so as to enable a setting of the variation to be made by means of a pointer against a scale. The compass unit is capable of rotation in order to bring the pointer into register with the variation figure and is then locked in position by means of a wing nut. All bearings and courses read off against the lubber line will then be "true." A magnifying prism is used but there is no centesimal scale.

Type O3.

Type O3 Compass is also designed primarily for the observer and has a centesimal scale. This obviates the necessity for a large compass card. The four damping filaments are marked 0, 1, 2, and 3, and register against a scale of 100° fixed to the side of the bowl. The markings on the filaments represent hundreds of degrees, and a reading is taken from the one which registers on the scale. Thus, if the filament marked 2 registers on the 24° mark on the scale, the reading is 224°. Another set of four filaments consists of sealed glass capillary tubes containing luminous compound and point N., E., S., and W. The N. filament carries an arrowhead. A short luminous tube acts as a lubber line. A rotatable azimuth[1] circle or verge ring is fitted above the bowl, and carries a glass prism through which the reversed markings on a small mica card (mounted on the magnet system) can be read. The azimuth circle can be locked in position if desired, and is made detachable.

[1] The azimuth is the angle between the bearing of an object and the meridian line.

TYPE O4.

Type O4 Compass is intended to be held at eye-level by the handle provided, while bearings are being taken. The object is "sighted," and

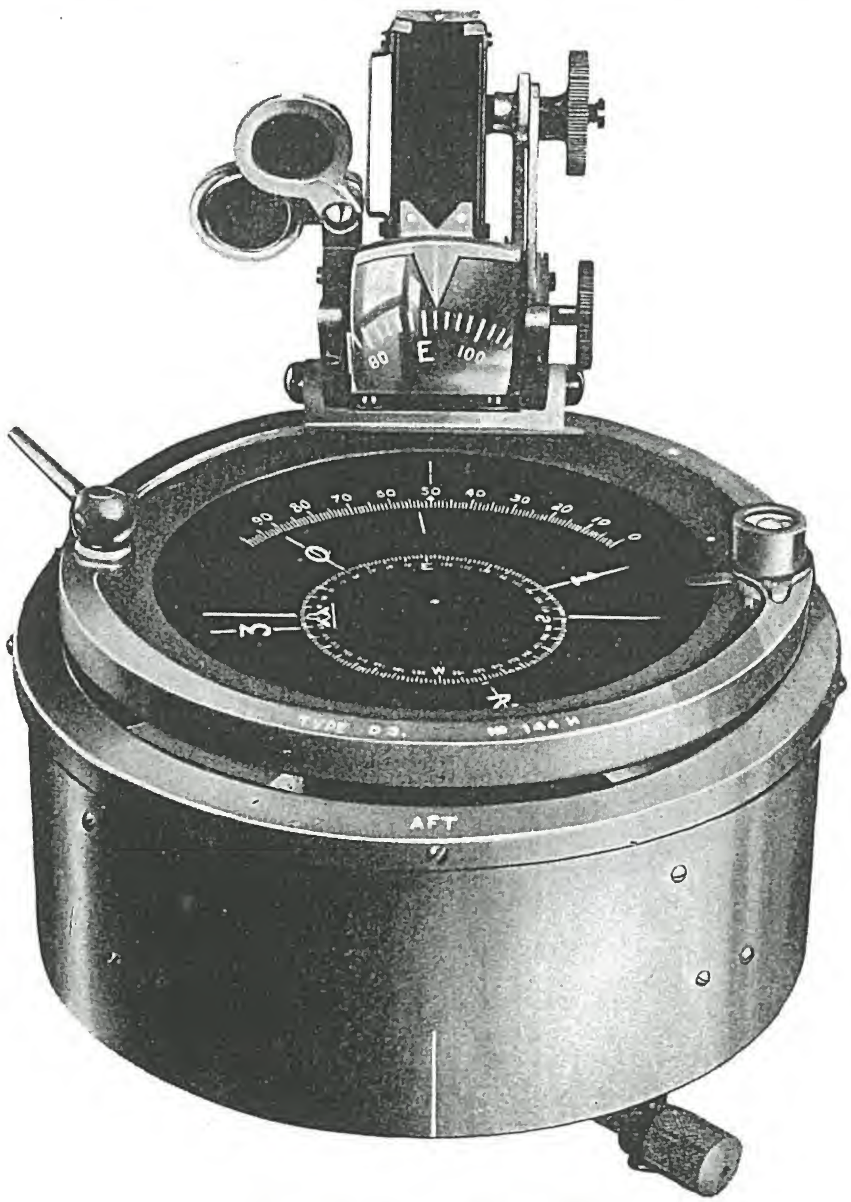


FIG. 53. COMPASS (TYPE O3)
(Henry Hughes and Son)

the bearing read off from the portion of the compass card which is seen through the magnifying prism. The handle is hollow and contains a small battery and lamp for illuminating the compass through the glass bottom of the bowl. A switch on the handle controls the lamp. A special

bracket is provided for convenient stowage or mounting in various positions in the aircraft.

TYPE P6.

The P6 type Compass is one of the same type as P4, but considerably smaller.

FIG. 54. COMPASS: "HUGHES" MARK IIIA
(Henry Hughes and Son)

TYPE "HUGHES" MARK IIIA.

The "Hughes" Mark IIIa Compass is fitted with a rotatable grid ring carrying four parallel grid wires. The scale is divided into 360° by 2° intervals. In setting a course the grid ring is rotated until the desired course shows against the lubber line. The grid ring is then clamped and the aircraft is steered in such a way as to keep the N.–S. pointer parallel to the grid wires, with the red arrow pointing to N. on the grid. Special suspension arrangements have been adopted in order to reduce the effect of vibration or shocks of landing to a minimum. Provision is made for the adjustment of the grid wires by turning a small slotted nut at the ends of the wires. A micro-adjuster is fitted to the underside of the compass bracket immediately beneath the centre of the compass, and is

operated by keys, one for fore-and-aft adjustment, the other for athwartships adjustment when correcting for deviation. This takes the place of the corrector magnets used in many other types.

Type K.B.B.4.

The K.B.B.4 type Compass, manufactured by Kelvin, Bottomley & Baird, is similar to P4 type, carrying four direction indicators and a

Fig. 55. Compass: Type K.B.B.4
(*Kelvin, Bottomley and Baird*)

graduated verge ring provided with parallel grid wires. By suitable choice of the weight acting on the pivot, the magnetic moment, and the moment of inertia of the damping elements, the "period" (the time which the magnet system takes to return to the equilibrium position after displacement to 90°) is reduced to $6\frac{1}{2}$ sec. and the overswing to 4°.

The compass is provided with inverted pivots, that is, the pivot point is carried by the moving magnet system, the jewel being carried in the central pillar. This is an advantage where the compass is subjected to much vibration.

Type Sestrel II.

The "Sestrel" type Compass, Mark II (made by H. Browne & Son), is also similar to P4. A special feature is the lightness of the magnet

system, which weighs only $1\frac{1}{2}$ grm. A micro-adjuster for correction of deviation is fitted, and there is also a locking device to prevent the possibility of movement of the magnets under vibration. The adjusting keys will only turn easily when two locking screws are slackened. On retightening these, the magnets are prevented from shifting.

TYPE "C," DENT & CO. & JOHNSON.

Dent & Co. & Johnson type "C" Compass is constructed on similar lines. The weight of the moving magnet system is $1\frac{1}{2}$ grm., and with 30° deflection the overswing is only $1\frac{1}{4}$°. The period is 6 sec. The interior of the bowl is blacked so that the luminized elements of the magnet system and the lubber line show up clearly in all circumstances. The compass is provided with the usual rotatable verge ring, with clamping device, and two parallel grid wires for setting parallel to the N. pointer of the magnet system.

The duties of the ground engineer in regard to compasses may be summarized as follows—

1. Inspection before installation.
2. Inspection after installation.
3. Supervision of swinging operations to determine the deviations.

Inspection before Installation

The compass must be examined visually before installation to ensure that it is in serviceable condition. This is not a difficult matter. Special attention should be given to the following points—

1. *Discoloration.* The compass must be reasonably free from discoloration of the card, the bowl, the liquid, or the cover glass. The discoloration is a brownish deposit or sediment due to the slow action of the liquid on the paint. A compass may be considered serviceable if the course can be read without difficulty under conditions of lighting which would be experienced normally in flight. It must not be forgotten that sediment collected in the bottom of the bowl may be thrown into suspension under vibration, and this effect should be taken into account. The bowl should not be dented as the enamel is likely to chip away at the dent.

2. *Pivot Friction.* Pivot friction is perhaps the most common defect in compasses, and a serviceable compass is reasonably free from this defect. The following simple test should be made. The compass should be supported on a level surface and the reading noted. If the compass is installed in the aircraft, the latter should be set approximately in flying attitude. A corrector magnet is then brought up close to the bowl, at right angles to the magnet system, thus causing a deflection of the latter to about 10°. The corrector magnet is then removed to a distance and the magnet system allowed to come to rest. If free from pivot friction, it will settle down to its original position. The compass may be considered serviceable if there is no more friction than can be eliminated by tapping the bowl with the knuckle—equivalent to the vibration of the aircraft. The friction is of the order of 1° at normal temperature. Discoloration is often associated with pivot friction.

3. *Anti-vibration Devices and Moving Parts.* The anti-vibration devices and all working parts should be examined for condition and freedom of

action. Verge rings and sighting mechanism should move freely. If the motion of the ring is not perfectly free, the ring should be removed and cleaned and lightly lubricated with a smear of vaseline mixed with powdered graphite. A broken spring must be replaced.

4. *Air Bubbles.* The bowl must be completely filled with the liquid recommended and supplied by the makers. Even a small bubble may result in a disturbance of the liquid ("liquid swirl") which causes the magnet system to oscillate, and makes it practically impossible to steer a correct course. This is especially serious in the case of aperiodic type compasses. If a bubble constantly forms there is probably a leak in the bowl or at a joint, or the liquid may not have been properly de-aerated before sealing.

De-aeration of Compasses

It is important that the liquid used in compasses shall be free from dissolved air, which is liable to form a large bubble when the external pressure is reduced, as in the case of a climb to a high altitude. The only satisfactory way of ensuring this is to de-aerate both the liquid (in the filled compass) and the filling-plug washers (which are made of compressed fibre and contain an appreciable quantity of air); then, to remove the bubble by filling up with de-aerated liquid and, finally, to seal up the compass.

The following standard method has been found to give entirely satisfactory results—

1. The expansion chamber beneath the bowl has a small tapped hole on its outer edge directly underneath the filling plug on the bowl. A small screw and washer to fit the hole should be at hand.

2. The compass should be filled in the ordinary way, and then placed in a suitable chamber, from which the air can be gradually exhausted by means of a pump. The apparatus is similar to that used for testing altimeters—described on p. 48. The compass should be placed so that the glass is vertical and the filling plug socket uppermost. The plug should be removed.

3. The filling plug washer and a small quantity of compass liquid should be placed in a beaker, and the beaker placed beside the compass in the chamber.

4. The pressure in the chamber is then reduced to about 2 in. of mercury, and the apparatus is left for at least one hour in this condition.

5. On removing the compass, the bubble caused by the de-aerating process is removed by carefully pouring in (without splashing) some de-aerated liquid from the beaker. This drives the air in the expansion chamber through the small tapped hole, and so completely gets rid of the bubble in it. The compass is then finally sealed, by screwing first the small screw with its washer, and then the filling plug with its washer, into their respective holes. This operation should be performed as quickly as possible (say in three or four minutes) as air is gradually re-dissolved so long as the liquid is exposed to the atmosphere.

6. The expansion chamber should be distended as required to allow for the temperature at which the compass has been filled. This precaution is not necessary if the expansion chamber has been previously given a permanent set to allow for filling at 15° C.

Compasses thus de-aerated have been subjected to a range of temperature from +15° C. to − 50° C., and to a range of pressure from 8 to 30 in. of mercury, without air bubbles forming.

Inspection after Installation

The inspection after installation should be carried out systematically, to ensure that—

(*a*) The compass is an approved type. Present types approved are: 6/18, P2, P3, P4, P6, O2, O3, O4, Hughes IIIa, K.B.B.4, Sestrel II, and Dent & Co. & Johnson "C," which have already been briefly described.

See also Civil Instrument Specification No. 9 (p. 132).

(*b*) It is positioned in accordance with the installation drawings.

(*c*) No damage has occurred during installation.

(*d*) No ferrous material has been employed for the support or platform, and that only brass fixing screws and bolts and nuts have been used.

(*e*) No part of the aircraft is in contact with the compass bowl.

(*f*) The attachment of the compass to the aircraft is rigid, and the magnet system is in the normal untilted position when the aircraft is in normal flying position.

(*g*) The vertical plane through the centre of the compass and the lubber mark coincides with (or is parallel to) the vertical plane through the fore-and-aft axis of the aircraft. The lubber mark should be to the front. In most compasses the fore-and-aft line is marked by white lines on the container, and usually the securing lugs have curved slots to permit slight rotation of the compass, if necessary in making any adjustment.

(*h*) If the corrector box is a separate fitting, it is placed centrally under the compass bowl, with the holes for the magnets exactly fore-and-aft and athwartships respectively. The fore-and-aft line usually marked by a line painted on the box.

(*i*) No added fittings of ferrous metal are near enough to the compass to affect its readings.

Deviations

A compass installed in an aircraft is subjected to disturbing influences due to the presence in its vicinity of iron and steel parts as well as electric circuits. It does not, therefore, give the same indication of a bearing as it would if removed from all such influences, and were influenced solely by the magnetic field due to the earth.

The correction which must be applied to the compass reading to obtain the true bearing is called the **deviation.** It is defined by the number of degrees which must be added (algebraically) to the observed reading of the compass in order to obtain the true magnetic bearing.

Thus, if the compass in an aircraft is headed to magnetic N. and reads 5°, the deviation is 5° West, or $-5°$, since $-5°$ must be added to the observed reading 5° to get the true bearing 0°. Again, if the aircraft is heading S. and the reading of the compass is 166°, the deviation is 14° East or $+14°$, since $+14°$ must be added to 166° to get 180°, the true bearing. (The compass is graduated 0 to 360° from the north point through E., S., and W., back to the north point.)

The deviation generally varies with the direction in which the aircraft is heading, and can be determined by aligning the aircraft on known magnetic courses in turn, and noting the readings of the compass on each course.

It is sufficient for the pilot to know the corrections for the compass at the **cardinal points** (N., E., S., and W.) and the **quadrantal points** (N.E., S.E., S.W., and N.W.), and these corrections can be determined by heading the aircraft successively to these points in turn. The results are conveniently arranged in the form of a table or curve fixed to the instrument panel in a position close to the compass.

Suppose the aircraft has been headed successively in the directions given in column 1 of the following table, and the corresponding readings have been noted as in column 2. The deviations are calculated as described above and tabulated in column 3.

	1	2 Compass Reading	3 Deviation
N. . .	0°	348°	+ 12° (E)
N.E. . .	45°	40°	+ 5° (E)
E. . .	90°	91°	− 1° (W)
S.E. . .	135°	142°	− 7° (W)
S. . .	180°	183°	− 3° (W)
S.W. . .	225°	227°	− 2° (W)
W. . .	270°	261°	+ 9° (E)
N.W. . .	315°	302°	+ 13° (E)

It should be clear that when the correction to be applied has a plus sign, the deviation is to the East of the magnetic meridian. A westerly deviation is always given a minus sign. It will be found more convenient to use the plus and minus signs rather than the terms East and West to describe the direction of the deviation.

These correction figures can be reduced considerably by introducing small bar magnets in the corrector box of compasses to which such a box is fitted. These corrector magnets, of length about 2 in., are usually made in four thicknesses, $\frac{3}{32}$ in., $\frac{1}{16}$ in., $\frac{1}{32}$ in., and $\frac{1}{50}$ in.

The Deviation Coefficients

All the possible magnetic effects in aircraft, due to various iron and steel parts and equipment, may be grouped into five distinct types. The appropriate corrections are called the approximate "coefficients," and are distinguished by the capital letters A, B, C, D, and E. The method of calculating these coefficients and their application will now be briefly described. For convenience they are dealt with in order, but in practice B and C should be calculated and correction made before A.

The deviation coefficient A corrects for—

(*a*) Incorrect setting of the lubber mark.

(*b*) Incorrect mounting of the card on the magnet system. This is called the *Card Error*.

(*c*) An unusual distribution of soft iron in the aircraft.

The coefficient A is the same on all bearings. It is calculated (from the figures given above) as follows—

$$\text{Mean deviation} = \frac{+12 + 5 - 1 - 7 - 3 - 2 + 9 + 13}{8} = \frac{+26}{8} = +3\tfrac{1}{4}^\circ$$

To correct for this, loosen the clamping bolts and turn the compass clockwise through $3\frac{1}{4}$°, reading the $3\frac{1}{4}$° from the compass, then reclamp. If the mean deviation had been negative, the compass would have to be turned anti-clockwise.

Correction A cannot be made for P3 or P5 types of compasses.

The deviation coefficient B corrects for magnetic effects which may be considered as similar to those which would be produced by an imaginary magnet placed in the fore-and-aft line of the aircraft. The greatest effects will be produced on the E. and W. bearings. B is half the difference

(algebraical) of the deviations on the East and West points, and is calculated from the figures given above thus—.

$$\frac{\text{Deviation on E.} - \text{deviation on W.}}{2} = \frac{(-1)-(+9)}{2} = \frac{-1-9}{2}$$
$$= \frac{-10}{2} = -5°$$

It is important to substitute the values for the deviations with their proper signs.

To correct for this, place one or more magnets in the fore-and-aft holes of the corrector box when the aircraft is heading E. or W., until the compass reading *changes* by as nearly as possible 5°. It should be clear that to correct for $B = -5°$, the blue (south-seeking) ends must be placed forward. To correct for $B = +5°$, the red (north-seeking) ends must be placed forward.

The deviation coefficient C corrects for magnetic effects which may be considered as similar to those which would be produced by an imaginary magnet placed athwartships in the aircraft. The greatest effects will be produced on the N. and S. bearings. C is half the difference of the deviations on the N. and S. points, and is calculated from the figures given above thus—

$$\frac{\text{Deviation on N.} - \text{deviation on S.}}{2} = \frac{(+12)-(-3)}{2} = \frac{+15}{2} = +7\tfrac{1}{2}°$$

each value being substituted with its proper sign as before.

The deviation coefficients D and E correct for the presence of soft iron magnetism in the aircraft. The greatest effects of D appear on the quadrantal points, and those of E on the cardinal points. These coefficients are not of particular importance and need not be considered here.

Just as the earth's magnetic field may be considered equivalent to that of an imaginary magnet with poles situated near to the earth's magnetic poles, so the magnetic field due to the presence of magnetic material in an aircraft may be considered as equivalent to that which would be produced by an imaginary magnet with its distinct poles in the aircraft. In other words the aircraft is considered as acting as a permanent magnet having the line joining its poles lying in some definite direction. The magnetic effect on the compass is the same as that of two imaginary magnets, one in the fore-and-aft axis and the other athwartships. These two magnets were referred to in the discussion of deviation coefficients B and C above.

Soft iron (that is iron which becomes magnetized in a magnetic field, but which does not retain its magnetism when removed from the field) may occur in various parts of the aircraft, and affect the compass on account of the magnetism induced in it by the earth's magnetic field. Its effects can be compensated by adjusting the position of soft iron spheres near the compass, as is customary on ships.

Adjustment of the Compass

It is advisable to adopt a definite routine in adjusting the compass, in order to economize both time and labour. The following preliminary precautions should be observed—

1. The compass should be examined as previously described. Any defects must be remedied or the compass must be replaced by one that is not defective.

2. All magnetic steel, tools, etc., should be removed from the aircraft, unless carried during flight in fixed positions.

3. All gear, such as wireless apparatus, which could possibly affect the compass during flight, should be in position.

4. All keys, magnets, etc., should be removed from the pockets.

5. The corrector box should be emptied of magnets and the latter removed to a distance.

6. The aircraft must be in normal flying position. The tyres must be equally inflated.

7. If more than one compass is fitted, readings and/or corrections of all compasses should be made on each bearing before moving the aircraft to the next bearing.

Adjustment by Use of a Landing Compass

The aircraft is set up in the open, at least 50 yd. away from masses of iron, such as hangars, railway lines, and 100 yd. from an electric or wireless generating station, or underground cable carrying a heavy current. Plumb lines are suspended from the centre of the propeller boss and the centre of the rudder post. The axis of flight of the machine will be in the vertical plane through both plumb lines. About 50 ft. to the rear and in line with the plumb lines the landing compass is placed in position and levelled. By sighting through the slot and hair-line of the compass on the plumb lines, the magnetic bearing of the aircraft is obtained. The difference between the magnetic bearing thus obtained and the reading of the compass in the aircraft gives the deviation. The aircraft is then swung round, approximately about a fixed pivot point, and the landing compass is moved to a new position, at about the same distance as before, and again aligned with the plumb lines. Local objects may often be chosen conveniently, lying approximately in the directions of the cardinal points, as determined by the landing compass. The aircraft is then placed in line with these objects in turn. Readings are taken in successive positions as before and the results are plotted on squared paper. A curve is then drawn from which the figures for the cardinal and quadrantal points can be obtained for recording on the deviation card.

Adjustment by Use of Swinging Base

At many stations a swinging base is marked out permanently, by eight lines radiating from a centre, in the directions of the cardinal and quadrantal points.

The aircraft is headed N., E., S., and W. in turn, and the deviation in each position recorded. The correction on the N.–S. line is then made as explained above (coefficient C). The aircraft is then headed W., the deviation is noted, and coefficient B is calculated, and correction made. The aircraft is then swung round so as to head to each of the eight directions in turn; the deviations are noted and correction is made for coefficient A if necessary. If the compass bowl is rotated in order to correct for A, it will be necessary to correct *all* the readings by the number of degrees through which it was rotated. Final readings should be taken when the engine of the aircraft is running, after which the corrections are entered up on the deviation card.

Swinging an Aircraft Afloat

It is sometimes necessary to determine the deviations when the aircraft is afloat. It will be clear that it is impossible to obtain the same degree of accuracy as on land. Obviously, the best time to choose is on a

calm day and at slack water between tides. One of the following methods may be employed—

1. *The Bearing Compass or Bearing Plate Method.* The aircraft is moored to a buoy and swung round into different positions in turn. From each position a bearing is taken of some prominent object—say three miles distant—by means of a bearing compass in the aircraft. Suppose the bearing is 356° when the aircraft is heading 72° E. The magnetic bearing is found from a chart to be 350°. The deviation is therefore - 6° E., and the true magnetic course of the compass at the time of observation was not 72° but 66°. Errors due to swinging and changes in relative position of aircraft and its mooring buoy are neglected. The bearings obtained in each position are plotted on a curve from which the corrections at the cardinal and quadrantal points can be read off and recorded on the deviation card.

A bearing plate may be used instead of the bearing compass. It must be fixed so that the line joining the lubber marks is parallel to the fore-and-aft axis of the aircraft. The zero mark must be adjusted to be in line with the forward lubber mark and the plate clamped in this position. Readings must then be taken from the foresight for different positions of the aircraft as when the landing compass is employed. For each position note the compass reading, which gives the angle between the fore-and-aft line of the aircraft and the magnetic meridian. The true bearings are found by adding (or subtracting) the bearing-plate readings to (or from) the corresponding compass readings. The figures so obtained can be compared with the chart bearings. The differences are the corrections of the compass and are plotted as before. A rough sketch showing the directions of true north, magnetic north, and the distant object should be made to decide whether the readings of the bearing plate must be added or subtracted from the compass readings.

2. *The Landing Compass Method.* A suitable position ashore is selected for the landing compass. It should be free from local magnetic interference. At a signal pre-arranged, simultaneous readings are taken of the bearings of (*a*) the landing compass from the aircraft, (*b*) the bearing plate or compass in the aircraft from the landing compass on shore, and (*c*) each compass to be adjusted. The aircraft is swung round as before into different positions, and similar sets of readings are taken in each case. The results may be conveniently set out in a table as follows—

1 Course by Pilot's Compass	2 Bearing by Bearing Plate	3 Sum of Columns 1 and 2	4 Landing Compass Reciprocal	5 Corresponding Magnetic Course	6 Deviation
318	2	320	323	321	+ 3 (E)
48	282	330	326	44	- 4 (W)

Whatever method is used for the adjustment, care must be taken finally to fasten the covers of the corrector box securely, to note particulars of the magnets used and the number of the engine in the compass log book, and to see that the deviation card is completed correctly and fixed near the compass.

Further details of the theory and the standard methods described above may be obtained from the various official handbooks.

*11. THE STATOSCOPE AND RATE OF CLIMB INDICATOR

The Statoscope

The Statoscope is an instrument for indicating small variations in altitude and is useful in maintaining flight at the same altitude or pressure level. For this purpose the ordinary aneroid form of altimeter is not sensitive enough.

The principle of one type—the Bubble Statoscope—is illustrated below. A "thermos" flask in a suitable container is connected with the curved glass tube seen near the top of the case. The tube contains a small drop of a mobile liquid, of low density, viscosity, and vapour pressure, usually

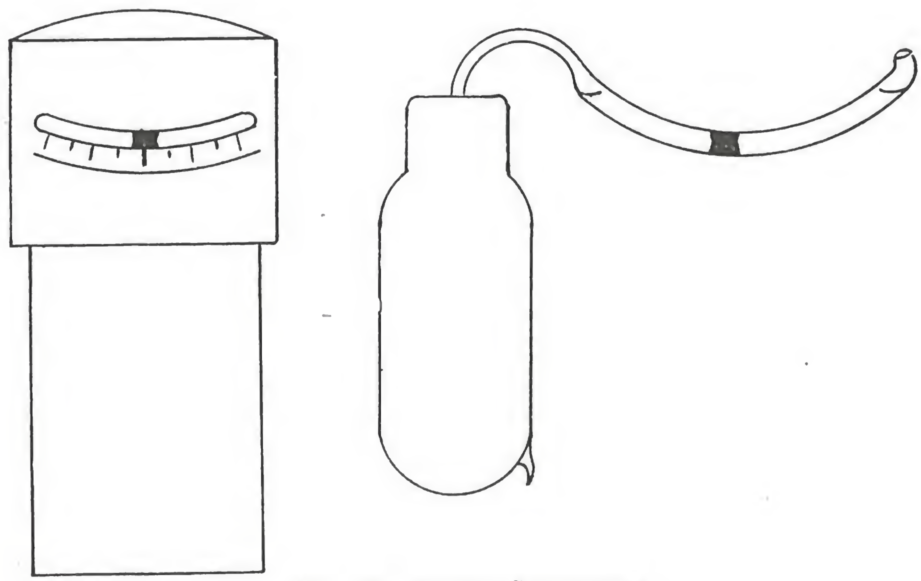


FIG. 56. BUBBLE STATOSCOPE

dyed red so as to be easily visible. The ends of the tube are enlarged or trapped to prevent escape of the liquid either into the external air or back into the thermos flask. As the aircraft rises into regions of reduced air pressure the pressure within the flask is greater than the external pressure. The liquid then moves up to the right-hand trap, where it breaks, allowing air to escape from the flask. When descending, the reverse happens. The liquid moves left, breaks, and air enters the flask. During level flight, the liquid remains stationary. The object of the thermos flask is to render the instrument insensitive to changes of temperature. A scale of sensitivity is sometimes provided and the sensitivity is such that a movement of the liquid from one scale division to the next is effected by change of pressure equivalent to ·02 m. of mercury corresponding at ground-level to 20 ft. and at an altitude of 10,000 ft. to 26 ft. difference in height.

In order to maintain level flight, the pilot endeavours to keep the liquid drop in the centre of the tube.

It should be noted that false readings are likely if the instrument is used in an enclosed cockpit.

In testing the statoscope, a small bubble, approximately ·2 in., is made with the liquid supplied for the purpose. The instrument is then placed in a vacuum chamber and the pressure reduced at the rate equivalent to

a rise of 1000 ft. per minute to 10,000 ft. During this test the bubble should move up to the right-hand trap, where it breaks allowing air to escape from the flask. When the pressure is increased the reverse happens, namely the bubble makes and breaks on the left. If there is a leak, the bubble will not make and break satisfactorily. The rubber connexions should be examined to verify that they are not perished or damaged, and each instrument should be supplied with a small bottle of red fluid, fountain pen filler and cleaning brush.

Rate of Climb Indicator

Rate of climb can be determined by observing the change in height in a given time. Direct measurements of height are impracticable and the method of pressure difference is usually adopted

The Rate of Climb Indicator utilizes the principle of the capillary leak. Two separate air chambers are provided with a capillary leak between them. One of the chambers is connected to the outer air by a tube connecting with the static line of the air speed indicator system. The indicator measures the pressure difference between the two chambers. This depends on the rate of climb and the scale is directly graduated in thousands of feet per minute. A screw marked "Zero return" fitted to the front of the instrument enables the pressure in the chambers to be equalized after a climb, by turning the screw anti-clockwise. The screw must then be turned clockwise to close the valve connecting the chambers, so that the instrument is left ready for use.

At the back of the case there is a zero-setting device which is protected by a screw which must be removed before the adjustment can be made. The pressure in the chambers should be equalized before adjusting the zero setting and care should be taken to replace the fibre washer under the screw.

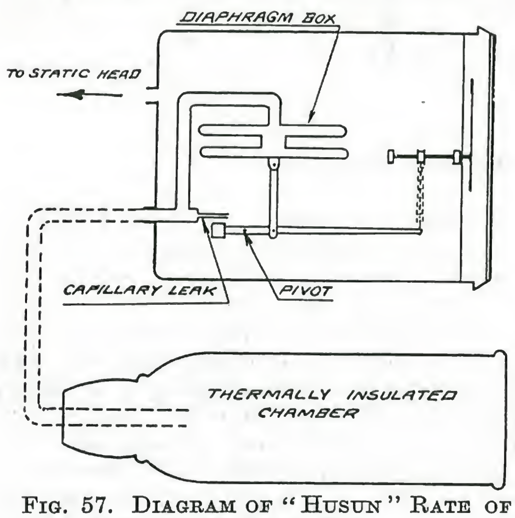


FIG. 57. DIAGRAM OF "HUSUN" RATE OF CLIMB INDICATOR
(Smith's Aircraft Instruments)

The pressure should always be equalized by manipulating the adjusting screw, before taking an observation. The instrument is very sensitive to changes of temperature, and it is important to neutralize in this way any difference of temperature between the indicator and the static line of the air speed indicator system to which it is connected.

Mark 1b Rate of Climb Indicator utilizes the capacity of its own case with a leak to atmosphere to obtain pressure differences.

Experience has shown that the best climb is obtained by keeping the air speed (as indicated by the air speed indicator) as constant as possible during the climb. Approximately the best climbing speed is at one-third of the speed range up to the stalling speed. Thus, if the top speed is 150 m.p.h. and the stalling speed 45 m.p.h., thebest climbing speed is about 80 m.p.h.

It should be noted that the rate of climb is the vertical component of

the velocity of the aircraft *relative to the air*. This is not necessarily the rate of rising from the ground, which may be affected by vertical currents.

*12. RECORDING INSTRUMENTS

It is often desirable to have a chart record of the changes in altitude, air speed, temperature, or other condition during a flight. For this purpose a number of instruments have been designed. One of these, the Tel Engine Speed Indicator and Recorder, has already been described.

In recording instruments, the mechanism is usually arranged to move a marking pen across a drum to which a paper chart can be attached. The drum is rotated by clockwork and the paper chart has a baseline marked in minutes and a vertical scale marked in suitable units.

Altitude Recorder

In the case of the Altitude Recorder, or Altigraph, the vertical scale is in thousands of feet. The drive is transmitted to the drum through a friction clutch, arranged so that no slip occurs when the drum is turning

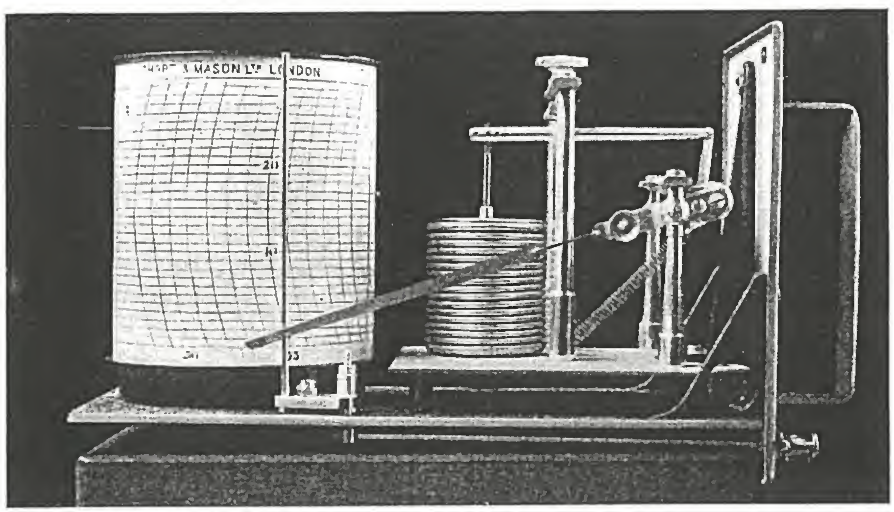


FIG. 58. ALTITUDE RECORDER
(*Short and Mason*)

while the instrument is operating. The drum, however, may be turned by hand when it is desired to set it to any required position. The clutch may be released and the drum removed for the purpose of replacing the paper chart. Adjusting screws are provided for varying the pressure of the pen on the chart and for setting the zero. A lever is provided for lifting the pen clear of the drum and at the same time stopping the clock. In preparing the Recorder, previous to a flight, the drum is removed and a new chart placed in position with its lower edge in contact with the bottom flange of the drum. The chart is slightly larger than the circumference of the drum, and should be arranged so that the overlap comes under the spring clip which keeps the paper in position. On replacing the drum, care should be taken to align the holes with the two driving pins on the friction plate. The securing nut should be tightened and the drum turned until the spring paper clip is immediately to the left of the pen.

The pen is then charged with the special ink provided and tested on a

piece of paper to ensure that the ink is flowing. See that the pen is correctly positioned on the pen arm, namely, pushed up to the shoulder. Adjust the pen on the zero line of the chart. Wind the clock and verify that it is set for the correct speed of rotation, if two speeds are provided. The positions of the speed change lever are clearly marked, and it must be operated only when the clock is not in motion. Start the clock by operating the starting lever to its fullest extent, when a spring catch will hold it in the ON-position. After use, clean the pen with blotting paper to prevent corrosion and consequent difficulty the next time the instrument is required for use.

Testing Altitude Recorders

Altitude Recorders are tested in the same way as altimeters (see p. 48). A large vacuum chamber will be required, however, of such a size as to accommodate the recorder and a sub-standard altimeter if a mercury barometer is not available. The vacuum chamber is connected through a tap to a reservoir, which can be exhausted by means of a small hand pump. Another tap opens to the atmosphere. The recorder is prepared as described above, but the pen should be set on the chart at a point corresponding to the reading of the barometer as shown by the sub-standard instrument. The clock should be started and the pen be marking satisfactorily before replacing the cover of the vacuum chamber or commencing the test.

A few strokes of the pump will exhaust the reservoir to such an extent as to make it possible to reduce the pressure in the chamber by an amount equivalent to 1,000 ft. in one minute, by manipulating the tap. The tap should then be closed and a few more strokes given to the hand pump during the following minute, which will be sufficient for the pen to record a short horizontal line on the chart. The process is repeated every thousand feet until the maximum is reached. Tests under gradually increasing pressure are then made in the same way, by operating the other tap which opens to the atmosphere.

The corrections applicable to the sub-standard instrument should be added algebraically to the errors indicated by the chart record.

After removal of the instrument from the chamber, the pressure in the reservoir should be released by opening the appropriate tap. The sub-standard should be allowed twenty-four hours' rest before it is used for another test.

Recording Pens (Boat type) give considerable trouble unless they are kept in good condition and adjustment. The following notes (compiled by Messrs. Negretti & Zambra) give some useful hints—

1. Clean the pen in methylated spirit with a brush; if necessary any clogged ink may be removed with a knife, taking care not to open the split.
2. When the pen is moist with the methylated spirit, run a piece of metal foil (not more than ·002 in. thick) in the split to clear out any clogged ink.
3. Fill the pen with the recording ink (supplied with the instrument) whilst it is still moist with the methylated spirit.
4. It is most important to prime the split thoroughly with ink. To ensure this, the piece of metal foil may be run along the split when the pen is full of ink.
5. When the pen has been well primed, it may be tested on a piece of paper before fitting to the instrument.
6. The main defects which arise from the boat type of recording ink pens are described in the following paragraphs Nos. 7 to 13.

7. Pen worn and split too open; ink will not flow.

8. Points not touching evenly; pen will not write.

9. Points too sharp and spread open; pen digs in and will not write.

10. Saw cut or split in wrong place; pen will not write.

11. Top edge of pen not level.

12. Split too wide; trace too thick.

13. Point too sharp; trace too thin; pen digs in paper.

14. The pen illustrated will give a good medium trace. The point should be well burnished and slightly rounded to prevent the pen digging in the paper; No. 00 emery paper may be used for slightly rounding the point.

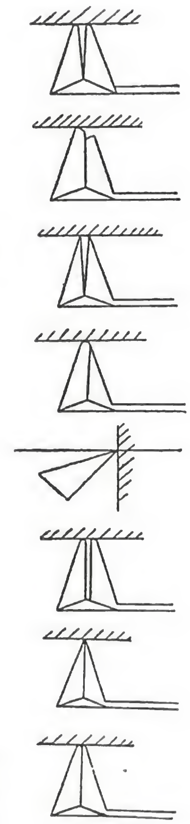


FIG. 59
RECORDING PENS

APPENDIX I

STANDARDS

A KNOWLEDGE of the use of sub-standards and standards and how to maintain their accuracy is essential for anyone engaged in the testing of instruments.

It should be clear that the accuracy of the standards used must be greater than that required for the instrument under test. Thus, in order to test an air speed indicator to an accuracy of, say, 1 m.p.h., the sub-standard manometer should be capable of measuring accurately at least $\frac{1}{2}$ m.p.h. At 100 m.p.h. this corresponds to a difference of head of water of about 1·25 mm. The reference standard used to check the sub-standard must therefore be capable of measuring a "head" of water to an accuracy of at least ·5 mm. (See Section on Air Speed Indicators, p. 40.)

The required accuracy for any particular instrument depends, of course, on the spacing of the markings and on the range. If reference is made to the table of approved types of pressure gauges (p. 12) it will be seen that with a range of 0 – 25 lb. per sq. in., the permissible error is ·8 lb. per sq. in., but an error of ·2 lb. per sq. in. is permissible with a range of 0 – 200 lb. per sq. in.

Consideration should always be given to the degree of accuracy required for the instrument under test, as well as the degree of accuracy of which the testing apparatus is capable. On test reports, it is usual to state the accuracy of measurement, thus, in the case of a thermometer, "Error at 98° C. is + 0·6°, to an accuracy of ± ·1°," means that the reading may be incorrect (either greater or less than the true amount) by an amount not more than ·1° C.; in other words, the true reading lies between 98·5° and 98·7° C.

SUB-STANDARDS

Sub-Standard Instruments

Some of the check methods which have been described above involve the use of another instrument (a sub-standard) known to be reasonably accurate. It cannot be too strongly emphasized that any sub-standard instrument (especially an altimeter or air speed indicator) should be most carefully handled, and never on any account used for any other purpose. A sub-standard instrument should be allowed a period of rest, say twenty-four hours before it is again used. Sub-standards should be tested periodically (say every three months) in a properly equipped testing laboratory furnished with ultimate standards. The check methods are to be regarded only as emergency methods to be employed when proper testing plant is not readily accessible.

APPENDIX II

ERRORS AND CORRECTIONS

THE difference between the terms "Error" and "Correction" applied to instruments is not always clearly understood.

The error is the difference between the observed reading and the true reading. If a gauge is tested against a master-gauge which reads 120 lb. per sq. in., when the gauge under test reads 125, the error of the latter is said to be + 5. If the observed reading is less than the true reading, the negative sign is used.

The correction at any point of the scale is the amount which must be added (algebraically) to the observed reading to obtain the true reading. In the above case, the correction to be applied to the observed reading 125, to obtain the true reading 120, is – 5, because – 5 has to be added to 125 to obtain 120. The correction is positive if added (numerically), and negative if subtracted.

Thus, the correction is always of opposite sign to the error, but is referred to the *observed* reading, whereas the error is referred to the *true* reading.

In the case quoted above—

(*a*) The error at 120 is + 5.

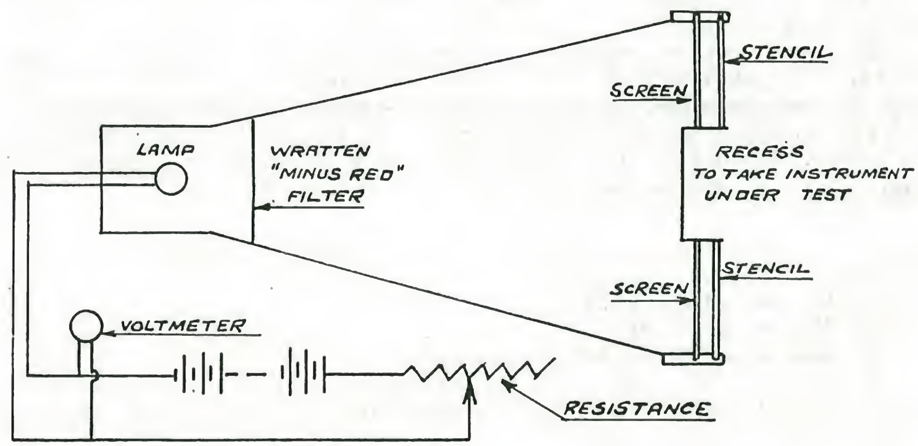
(*b*) The correction at 125 is – 5.

If the gauge had read 115 for a true pressure of 120, the error at 120 would have been – 5, but the correction to be applied to the observed reading 115 would be + 5.

APPENDIX III

LUMINOUS COMPOUND AND ITS APPLICATION

LUMINOUS compound consists of zinc sulphide suitably prepared and mixed with radium salt as short a time as possible before the compound is required for actual use. The luminous effect is produced by the action of Alpha rays, emitted by the Radium, on the particles of zinc sulphide.



APPARATUS FOR TESTING LUMINOUS DIALS[1]

FIG. 60

Mesothorium or a mixture of mesothorium and radium is sometimes used instead of radium.

When applying the compound, care must be taken to ensure that the surface to be luminized is free from grease and has a matt finish. The markings to be luminized are prepared with a coat of zinc white paint (free from lead). evenly applied and allowed to dry, before a coating of copal varnish is applied freely over the surface to be luminized. While this coat is still tacky, the luminous compound is applied over it by means of a pointed piece of pegwood. The luminous compound is prepared by mixing with gum arabic solution (1 oz. to 1 pint of water) to the consistency of cream.

When mesothorium is used the markings, after luminizing, should have a luminosity of at least 40 per cent of the N.P.L. Standard which is ·015 equivalent ft. candles, i.e 80 per cent of the R.A.F. Standard, which is ·0075 equivalent ft. candles.

[1] In this diagram, each stencil and screen should be tilted so as to be normal to the line joining the centre of the lamp to the centre of the screen.

LUMINOSITY TESTS

Tests on luminosity are carried out by a comparative method developed at the National Physical Laboratory.

Light from a standard lamp placed at the end of a box passes through a Wratten (minus red) filter, and falls on two translucent diffusing screens at a distance of about 3 ft. from the source as in Fig. 60. In front of these screens are placed stencils so cut that the emergent light corresponds to the luminous markings of the instrument under test, which is placed in the recess between the stencils.

The current passing through the lamp can be varied by a rheostat in the circuit, and a voltmeter records the voltage across the terminals of the lamp.

Previous to testing, instruments should be kept in the dark for a few hours. Exposure to light causes a temporary increase in luminosity and it is essential that measurements be made under similar conditions.

During a test, the illumination of the stencils is gradually raised by cutting out resistance on the rheostat until the light emitted matches the luminized markings on the instrument. With a little practice, the matching point can be determined with reasonable accuracy. The reading of the voltmeter is then taken, and the luminosity figure is obtained from the table provided by the National Physical Laboratory, where the apparatus must have been previously calibrated.

APPENDIX IV

VIBRATION TESTS

It cannot be too strongly emphasized that the instruments used in aircraft are necessarily of a highly specialized nature. They are specially designed to stand up to very severe conditions of service. They are subjected not only to continual vibration during the whole time the engine is running, but to severe shocks in landing and when taxi-ing over the ground. They are expected to function whatever the position of the aircraft, to withstand reduced pressures at high altitudes, as well as a range of temperature altogether unusual in instruments used for any other purpose.

By placing one hand lightly on the instrument panel when the aircraft is taxi-ing over the ground, or during flight when the engine is running, the type of vibration to which the instruments are subjected may be realized. It will be found to be much greater than would be anticipated by anyone who has not made the experiment. It is not possible to eliminate all the effects of jolts and shocks and vibration, but they may be much reduced by the use of shock absorbers, spring mountings, and felt or horsehair insulation. It is important that these anti-vibration devices should be effectively fitted.

Vibration tests were instituted in order to reproduce vibrations of the same character as those likely to be experienced in aircraft. The intensity of vibration actually obtainable is greater than is met with in actual practice, but not such as to throw undue strain on the instruments under test.

It is a definite requirement in all the Civil Aircraft Specifications that instruments shall be so proportioned and constructed that the vibrations experienced on an aircraft do not seriously affect the readings, impair the accuracy, or cause undue wear. All pins, screws, nuts, etc., must be secure against working loose under vibration. This necessitates the careful balancing of all the moving parts (to prevent excessive pointer oscillation), and the secure fixing of all adjustable parts, pins, screws, etc., so as to prevent any parts working loose. Vibration tests should also reveal any weakness which would cause failure due to breakage.

The tests are conveniently carried out on a specially constructed vibration table. The instruments are mounted on the panel and firmly secured in position by clips. The panel is rotatable between two uprights, and can be secured by wing nuts in a position inclined at any angle to the horizontal. The uprights are fixed to an horizontal board mounted on four springs anchored to a rigid base. In a central aperture of the panel, an eccentric weight, set in a suitable frame, can be caused to rotate by a flexible shaft, driven by an electric motor, of which the speed can be controlled by an adjustable resistance. The frame carrying the weight can be turned so that the weight can be rotated in a plane inclined at any desired angle to the instrument panel. The magnitude of the turning weight and its position on the radial arm can be varied, so that when rotating at 1,800 r.p.m., in the same plane as the instrument dials, the amplitude of the instrument panel is approximately 0·03 in. The amplitude can be judged by fixing strips of paper to the panel in two directions at right

angles. Small circles and spots of suitable sizes are marked on the strips. Under the conditions stated above, the spots will appear to describe circles, indicating that the vibration is circular in form. For any one position of the weight and a given speed of rotation, the amplitude will depend on the total mass of the instruments and panel. The amplitude should therefore be checked, when different types of instruments are under test. The panel should be uniformly loaded with four instruments, or if

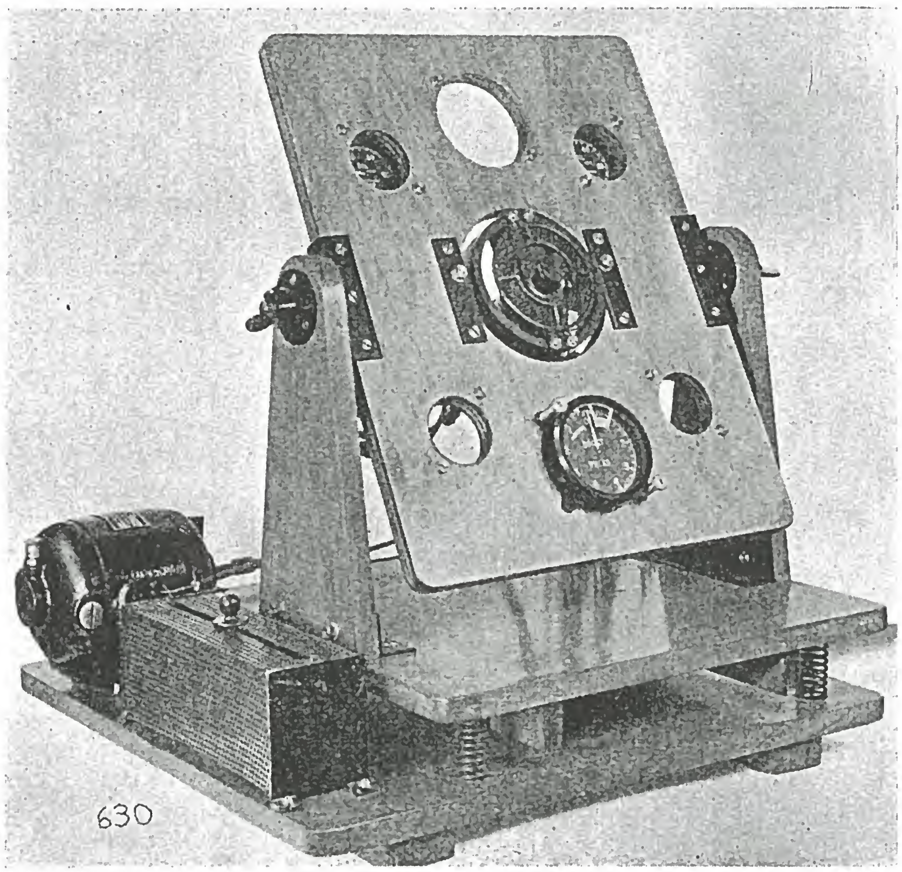


FIG. 61. VIBRATION TABLE
(*Negretti and Zambra*)

less than four are tested at a time, their equivalent in mass. It is important that the rotating weight should be perfectly free to rotate, as undue friction will radically alter the character of the vibration. If plain bearings are used, they must be kept well lubricated.

Tests should be carried out systematically in the following order—

1. With the dials in a vertical plane, and the frame of the "weight" adjusted so that the weight rotates in a plane parallel to the dials, the frequency should be varied from 1,200 to 2,200. The instruments should be caused to function over their complete range, and the behaviour of the pointer observed throughout the tests over a period of at least 10 min. Frequencies which give rise to resonance should be avoided.

2. The test should be repeated with the complete panel still vertical, but the weight adjusted to rotate in an horizontal plane.

In the above tests, the maximum amplitude is obtained by allowing the panel to vibrate freely. By gripping the panel with the hands the form and amount of the vibration can be varied. It is desirable to vary the vibration in this way in testing sample instruments of new design.

3. With the dials vertical and the weight rotating on a plane parallel to them, and at a frequency of 1,500 and amplitude of 0·03 in., a prolonged test is carried out over a period of at least 20 hours.

4. The test should be repeated after adjusting the plane of rotation of the weight to a position at right angles to the plane of the dials.

The last two tests are primarily for robustness of the design, and a check of the calibration should be made on completion of the test and the results compared with its previous record.

If carefully carried out, vibration tests yield valuable information as to the causes of pointer oscillation, unbalanced parts, insufficient control, and, if present, points of weakness and careless workmanship due to insecure fixing of pins and screws.

APPENDIX V

HIGH AND LOW TEMPERATURE TESTS

In addition to the tests on instruments at normal room temperature, tests at high and low temperatures are often desirable. Instruments may be required to function without permanent derangement in tropical climates, where the temperature may rise as high as 60° C. On the other hand, they are frequently exposed to extreme cold at high altitudes, where the temperature may fall in exceptional circumstances to – 60° C. In the case of civil aircraft, however, the lower limit of temperature is seldom less than – 20° C., and instruments are normally tested to – 5° C. only.

The behaviour of instruments at temperatures above and below normal is, therefore, a matter of considerable importance. The general effects of a change of temperature may be summarized thus—

1. Expansion or contraction of parts affecting clearances, thus introducing friction. A low temperature may cause a cover glass to become loose and even to fall out of the bezel.

2. Changes of elasticity, as in the case of metal diaphragms and springs.

3. Changes in viscosity of lubricants, where they are employed, introducing friction at low temperatures.

The tests at temperatures above and below normal involve the use of elaborate apparatus usually found only in a well-equipped laboratory. Full details cannot be given here, but the following brief particulars will give some indication of the methods commonly used.

Tests at temperatures above normal are usually carried out in some form of chamber (such as an incubator) in which the temperature can be controlled within definite limits by means of a thermostat. The chamber may be fitted with a tray of water and the humidity also controlled by a hygrostat, thus reproducing humid tropical conditions. A fan is necessary in order to keep the air within the chamber circulating, and to ensure that the whole volume of air is at the temperature indicated.

Low temperature tests are usually carried out in a chamber, the air in which is maintained at a temperature below 0° C. by means of a refrigerant circulating in piping round the air space. Carbon-dioxide is often used for the purpose. The gas is liquefied by a compressor plant at a pressure equal to about 70 atmospheres, and then passed through a series of pipes, surrounded by a water-jacket, and constituting a condenser system. The liquid CO_2 passes from the condenser through a regulator (which regulates the pressure) into the evaporator, where evaporation takes place. During this process, the heat required for the change, liquid to gas, is abstracted from the lagged chamber through which the evaporator coils pass. After evaporation, the gas returns to the compressor to undergo re-compression and subsequent liquefaction and evaporation. The cooling process is therefore cumulative. The cycle of operations is continuous and the same gas is used repeatedly. For testing small numbers of instruments for civil aircraft a "Frigidaire" or other similar plant may be used, and on a small scale the use of a simple freezing mixture is suitable.

FREEZING MIXTURES

Composition (by Weight)		Reduction of Temperature obtainable, ° C.
Ammonium Nitrate . Water . . .	1 1	25
Sal-ammoniac . . Ammonium Nitrate . Water . . .	5 5 16	22
Snow or pounded ice . Common Salt . .	2 1	22
Snow or pounded ice . Common Salt . . Ammonium Nitrate .	12 5 5	31
Snow or pounded ice . Calcium Chloride .	2 3	45
Snow . . . . Dilute Sulphuric Acid .	3 2	30

Of these, ice and salt is the cheapest and has a greater thermal capacity than mixtures not containing ice, that is to say, the quantity of heat absorbed is greater than in the case of equal weights of other mixtures. This is due to the greater latent heat of fusion of ice. It should be clearly understood that the temperature obtained is no guide as to the quantity of heat absorbed.

Small amounts of solid carbon-dioxide can be obtained from the ordinary CO_2 cylinders by tying a flannel bag two or three layers thick over the exit nozzle of the inverted cylinder and opening the valve. The solid CO_2 snow collects in the bag. Its temperature is about $-90°$ Cf. and it is soluble in methylated spirit, so that by dissolving suitable amounts in a quantity of the spirit the resultant temperature of the solution can be regulated.

In using freezing mixtures, care must be taken to prevent any part of the instrument coming into direct contact with the constituents of the mixture.

A temperature of $-60°$ C. is most conveniently and quickly obtained by using liquid oxygen, which is allowed to boil off and circulate through the cooling coils surrounding the chamber. In all cases, it is essential to ensure by means of a fan (or by constant stirring in the case of liquids) that the air or liquid is kept circulating, and to allow the instruments under test to "soak" for a period of 20 min. or half an hour to ensure that all parts attain the temperature measured by the thermometer, which forms part of the equipment.

The errors permissible at low temperatures are greater than those allowed at normal temperatures, and reference should be made to the relative specification for information on this subject.

One particular application of a low temperature test may be noted here. The only method of ascertaining whether a radiator thermometer (see p. 24) filled with ethyl-ether or some similar liquid is correctly filled

is to apply a low temperature test. The system should contain only ethyl-ether liquid and its vapour. If carelessly filled, residual air or moisture may be present, the effects of which become apparent when the gauge and capillary are cooled to a temperature below freezing-point, while the bulb is at a temperature of between 60° and 70° C. The presence of air will be indicated by much lower readings than those obtained at normal temperature. Moisture in the form of water or water vapour will freeze in the tube, and, as a result, the instrument will cease to function.

A testing cabinet for high and low temperature tests with a range from + 60° to − 60° C. has been produced by the "Korect" Depth Gauge Co. The refrigerating agent is solidified CO_2, which can be readily and cheaply obtained under the trade name of "Dry Ice," and is handled without danger, provided rough leather gloves are worn. The cabinet is carefully insulated and the central metal chamber is capable of accommodating six air speed indicators of the usual size, and thermometers for observation of temperature. The central chamber is enclosed with a plate-glass lid and along each of its sides, external to the chamber, run metal galleries on which the refrigerant, in the form of small lumps, is placed.

With this apparatus the temperature of the inner chamber can be reduced to − 20° C. in about 30 minutes, and maintained at this temperature for at least half an hour. Further reduction of temperature to − 60° C. can be obtained by removing the lid, repacking the galleries with the refrigerating agent, and closing down for about three-quarters of an hour. This temperature may be maintained by occasional additions to the refrigerant.

A separate insulated chamber is used to store the solidified CO_2 and is fitted with a coil system, so that it can be used as an auxiliary to the cabinet, when a low temperature has to be maintained for several hours.

Provision is made for carrying out high temperature tests in the same chamber by means of heating lamps, a temperature of + 50° C. being obtained in about 40 minutes. Special drying cells are provided. An air fan, rotated by a small motor mounted outside the cabinet, keeps the air in the chamber in circulation and at an approximately uniform temperature.

In all cases, an instrument should be allowed to remain in the hot or cold chamber at least twenty minutes before any readings are taken. This will ensure that the whole instrument is brought to the temperature of the chamber.

A drying tunnel is a useful additional piece of equipment and avoids the possibility of damage to instruments through condensation of moisture inside the case. The tunnel is approximately 4 ft. in length and a foot square in section. A suction fan at one end draws air through the instruments placed in the tunnel. The air is heated by four electric lamps at the other end and dried by passing through a double screen shutter containing silica gel.

*APPENDIX VI

THE ISOTHERMAL AND I.C.A.N. CONVENTIONS

THE limitations of the aneroid type of altimeter as a height measurer have already been pointed out (see p. 50). The instrument has to be calibrated on some agreed basis as to the variation of pressure with height. The temperature at different heights is continually changing and no assumptions can be made which apply strictly to the actual conditions at the time of observation. The readings of the altimeter must therefore be corrected for temperature if a reasonably correct estimate of height is desired. The temperature of the air is measured by a special type of thermometer, fitted to a strut (see p. 28) and the observed reading is used to correct the reading of the altimeter (calibrated isothermally) by means of a Computer (see p. 100). There are two methods of calibrating altimeters.

The Isothermal Convention

This assumes that the temperature at all heights is constant and 10° C., and that the pressure varies with the height according to the formula—

$$H = 62{\cdot}580 \log_{10} \frac{P_0}{P}$$

where H = height (thousands of feet)
P = pressure at height H
P_0 = the ground pressure.

The I.C.A.N. Convention

The International Commission for Air Navigation adopted a convention which takes into account variations of temperature with height, as explained on p. 34. It is assumed that the temperature falls uniformly at the rate of 1·98° C. per 1,000 ft. from 15° C. at ground level to – 56·5° C.

Note. STANDARD GROUND PRESSURE is taken as that due to a column of mercury 760 mm. **29·921 in.**) in height at 0° C in Latitude 45°. Mercury under these conditions is referred to as "Standard Mercury." It is necessary to specify the temperature and latitude, since the density (and therefore the weight) of a column of mercury varies with these conditions.

Another unit, the millibar, is now commonly used, in meteorology. **The millibar** is one-thousandth part of the **BAR,** which is a unit of absolute pressure, equal to 1 megadyne per sq. cm. Thus 1 millibar = 1,000 dynes per sq. cm.

Standard Ground Pressure, namely, 760 standard mercury millimetres (or 29·921 standard mercury inches), is equal to **1013·2 millibars.** This is the standard ground pressure according to both the isothermal and I.C.A.N. conventions. Previous to the introduction of the I.C.A.N. Convention, standard ground pressure was taken as **29·90 mercury-inches.**

Under **London Laboratory Conditions** (16·6° C. or 62° F., Latitude 51½°, standard ground pressure is **29·994 mercury-inches** (761·62 mercury-millimetres).

A standard mercury column can be graduated to read inches, millimetres, millibars, or equivalent heights, (according to either the isothermal or I.C.A.N. convention). It is usual to graduate the brass scales to read true inches (or mms.) at 16·6° C.—the standard temperature of the Imperial Standard Yard. If used at any other temperature, a correction must be applied. At 0° C. in Latitude 45° a pressure of 1013·2 millibars would be indicated by a reading **29·930** in. and not 29·921.

at 36,090 ft.; and that above this height (namely, in the stratosphere) it remains constant at $-56{\cdot}5°$ C. This is not necessarily the most accurate relation between temperature and height, but it does represent approximately the general average conditions all over the world and is a great improvement on the Isothermal convention which assumes a constant temperature of 10° C. (283° Absolute) for all heights.

The I.C.A.N. convention is as follows—

P_0 = ground pressure in millibars (taken as 1013·2 mbs.)
P = pressure at height H in millibars
H = height in thousands of feet
P_1 = pressure at 36,090 ft. calculated from the formula—

$$\frac{P_0}{P} = \left(\frac{288}{288 - 1{\cdot}98\,H}\right)^{5{\cdot}256}$$

which holds for heights up to 36,090 ft. For heights above this figure, the formula:—

$$H = 36{,}090 + 47{,}900 \log_{10} \frac{P_1}{P} \text{ is used.}$$

These formulae are based on the assumption that for heights between ground level and 36,090 ft. the temperature is $15 - 1{\cdot}98\,H$, and that for heights above 36,090 ft. the temperature is constant and equal to $-56{\cdot}5°$ C.

From the formula quoted above, tables can be drawn up showing the relation between: (*a*) the height, (*b*) the equivalent barometric pressure at that height, and (*c*) the temperature at that height, according to the I.C.A.N. convention (see Cols. 1, 2, and 3 in the table, p. 98). By means of these tables an altimeter can be calibrated directly in terms of height.

The equivalent barometric pressures in Col. 2 are calculated for London Laboratory Conditions. The permissible errors for various ranges are shown in Cols. 4, 5, 6, and 7 of the table.

It must be emphasized again that these "Permissible Errors" are those allowed under the standard conditions of test, namely, a reduction (or increase) of pressure at a rate equivalent to an ascent (or descent) of 1,000 ft. per minute. They include the "lag" (see p. 48).

Calibration of an Altitude Recorder

As an illustration of the method of using these figures, the calibration of an Altitude Recorder to the I.C.A.N. scale will now be considered. The instrument has to be calibrated to indicate the heights shown in Col. 1 at the barometric pressure in Col. 2 and the temperature in Col. 3 (p. 98).

In practice the temperature may be within 10° of the value in Col. 3, except at zero height, when this figure is taken at 20° C. (namely, $-5°$ C. to $+35°$ C. diminishing *pro rata* to 10° C. at a height of 5,000 ft.

Now it is not an easy matter to adjust the conditions of pressure and temperature, exactly to the figures given in successive lines of Cols. 1, 2 and 3 of the Table, so that the heights recorded on the chart of the instrument can be compared with the values in Col. 1 and the errors noted. A simpler procedure will now be described, the figures being taken from an actual test report.

Two series of readings, one at room temperature (say 21° C.) and the other at a lower temperature (say $-25°$ C.) are taken and the results tabulated. See Cols. A and B in Table on p. 99. The difference in the readings

TABLE OF PRESSURES AND TEMPERATURES AT THE HEIGHTS GIVEN IN COLUMN 1

(I.C.A.N. CONVENTION)

1	2	3	4	5	6	7
Height thous. of ft.	Press. Inches of Mercury at 16·6° C. and at latitude 51½°	Temp. Centigrade	Approx. Permissible Errors in Feet			
			Range to 10,000 ft.	Range to 20,000 ft.	Range to 30,000 ft.	Range to 40,000 ft.
1	31·09	17·0	35	140	200	270
0	29·99	15·0	40	150	210	280
1	28·93	13·0	45	160	220	290
5	24·96	5·1	65	200	260	330
10	20·63	− 4·8	90	250	310	380
15	16·93	− 14·7		300	360	430
20	13·78	− 24·6		350	410	480
24	11·63	− 32·5			450	520
30	8·91	− 44·4				580
40	5·55	− 56·5				680

	A	B	C	D	E	F	G	H	I
Temp.	21° C.	– 25° C.	Difference for 46° C.	Difference for 1° C.	I.C.A.N. Temp.	Temp. Diff. from I.C.A.N.	Difference for I.C.A.N.	Calibration for I.C.A.N.	Correct for Zero
Baro. Equiv.	– 180 ft.	280 ft.							
1,000 of ft.	ft.	ft.	ft.	ft.	°C.	°C.	ft.	ft.	ft.
Up. 0	Nil	– 70	– 70	– 1·52	15	6·0	– 10	– 10	Nil
5	– 50	– 160	– 110	– 2·39	5·1	15·9	– 40	– 90	– 80
10	– 30	– 160	– 130	– 2·83	– 4·8	25·8	– 75	– 105	– 95
15	+ 10	– 120	– 130	– 2·83	– 14·7	35·7	– 100	– 90	– 80
20	Nil	– 180	– 180	– 3·91	– 24·6	45·6	– 180	– 180	– 170
Down 15	+ 80	– 170	– 250	– 5·43	– 14·7	35·7	– 195	– 115	– 105
10	+ 50	– 160	– 210	– 4·57	– 4·8	25·8	– 120	– 70	– 60
5	+ 10	– 150	– 160	– 5·48	5·1	15·9	– 55	– 45	– 35
0	+ 40	– 50	– 90	– 1·95	15·0	6·0	– 12	+ 28	+ 38

for the change of temperature (i.e. 46° C.) is recorded in Col. C, from which can be calculated the difference in reading (feet) per degree C. change of temperature—Col. D. The readings at the corresponding I.C.A.N. temperatures can now be calculated by proportion.

The I.C.A.N. temperatures are set out in Col. E of the Table. The differences between these temperatures and the room temperature (i.e. 21° C.) are set out in Col. F and the corresponding height—differences in Col. G are calculated by multiplying the figures in Col. D by those in Col. F. Adding the results to Col. A, we obtain the calibration figures for the I.C.A.N. scale of temperature (Col. H). Correction for zero can be made by adding 10 to each figure in turn and thus obtaining Col. I which gives the reading at each height at the temperature specified by the I.C.A.N. relation for that height.

The reader who wishes to gain a clear understanding of the principles and methods involved in the determination of height and the calibration of altimeters is urged to work through the above calculations. The subject is an intricate one and must be carefully studied if a thorough grasp is to be attained.

The Computer consists of a circular flanged base plate approximately 6 in. in diameter, on the rim of which are engraved two scales, one of temperature, the other of height. A second concentric disc of smaller diameter, carries logarithmic scales of height and air speed and can be rotated relative to the larger disc by means of a milled head at the centre.

The instrument is used to obtain corrections to the readings of either the altimeter or the air speed indicator. Adjustable interlinked pointers can be set to the readings of the air thermometer and altimeter (or air speed indicator) and the corrected values are read off on the appropriate scales.

If a Computer is not available, corrections may be applied to the readings of an altimeter, calibrated according to the isothermal convention in the following way—

During a climb to height H as indicated by the altimeter, the air temperature t is observed at some intermediate height H_t as noted on the altimeter. H_t should not be near ground level, where large variations of temperature may occur. The correction to be applied to the reading at H is given by the formula—

$$\text{Correction} = 1{,}000.\ \ H\{0{\cdot}0031\ (2H_t - H) + 0{\cdot}0035\ (t - 10)\}\text{ft.}$$

H and H_t being in thousands of feet.

The reader should apply the formula to show that the correction at 30,000 ft. is – 2,220 ft. when on the climb the air temperature was – 20° C. at 20,000 ft.

The correction to be applied to an altimeter calibrated to the I.C.A.N. convention may be obtained from the corresponding formula—

$4(2H_t + T - 15)\ H$ ft., which applies only up to 36,090 ft. In the case cited above, the correction will be found to be 600 ft. instead of – 2,220 ft.

*APPENDIX VII

THE GYROSCOPE[1]

THE principle of the gyroscope enters into the design of several types of turn indicators and as its behaviour presents considerable difficulty, a brief description of the phenomena is given here. A complete explanation involves considerable knowledge of mathematics.

Consider a wheel (having for its size a very heavy rim) free to spin about its axle (Fig. 62A). Suppose it is caused to spin rapidly. We find that it offers considerable resistance to any attempt to change its speed of rotation. This is easily proved if an attempt is made to grip the rim. Consider a small portion of the wheel at P of mass m at a distance r from the centre O. P is constrained by the rotational motion to move in a circle (radius r) with velocity, say, V and is therefore subject to a force F (centripedal force) directed inwards towards O.[2] Regarding the rim as composed of a large number of small masses such as m disposed as the links of a chain, maintained in a rapid circular motion, each is acted upon by tensions T, T due to its neighbours. These tensions act at a very small angle to one another and are of considerable magnitude. The irresolved parts along the radius constitute the force F. Any attempt to deflect the mass at P from its circular path will meet with great resistance, as it will be necessary to overcome the resolved parts of these tensions which would immediately be brought into play.

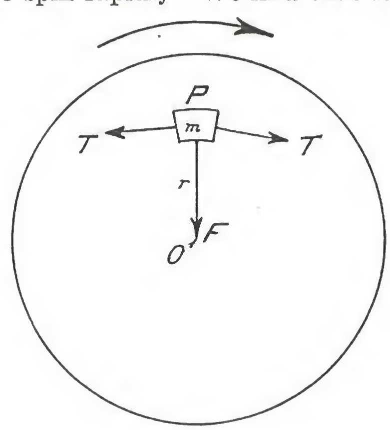


FIG. 62A

Further, the spinning wheel offers great resistance to any attempt to change the direction of its axis. This can only be brought about by applying twisting forces, constituting a **Torque.** The torque is measured by the moment of the forces about the axis of twist.

Suppose that, while the wheel is spinning about the axle WE, the axle itself is rotating in space (about a vertical axis perpendicular to the plane of the diagram) so that it occupies successively the positions $W_1 E_1$, WE, and $W_2 E_2$ (Fig. 62B). Such a rotation is called a precessional motion. The axle is said to precess about the axis of precession, which, in this case, is perpendicular to the plane of the paper.

The forces which would produce such a **Precession** will now be considered. Let P be a point on the edge of the rim of the wheel above the plane of the paper. When the axis is in the position WE, P lies in the meridian. A moment earlier, when the axis was in the position W_1E_1, P was to the east of the meridian. A moment later, the axis occupies the

[1] *Spinning Tops and Gyrostatic Motion,* by H. Crabtree is recommended for the student. A popular account is given in *Spinning Tops* by Perry (Romance of Science Series).

[2] For proof, see any textbook on Dynamics.

position W_2 E_2 and P is still east of the meridian. The path of P is therefore a curve P_1 P P_2. Thus P is acted upon by a force eastwards. Similar

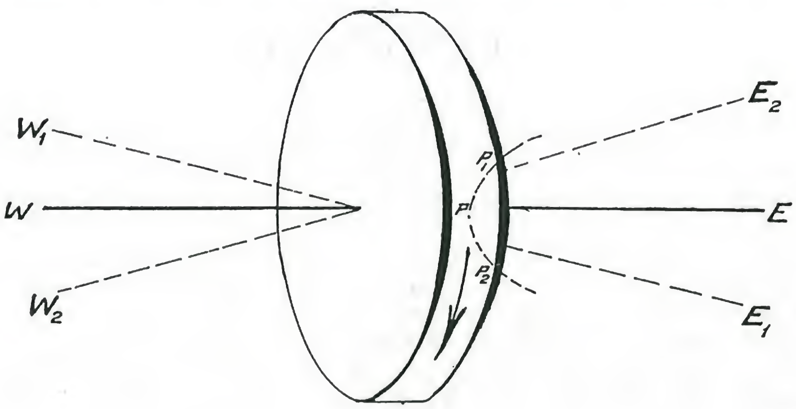


Fig. 62B

reasoning shows that the corresponding point on the other side of the rim describes a curved path concave to the west, and is therefore acted upon by an equal force to the west. These two equal and opposite forces con-

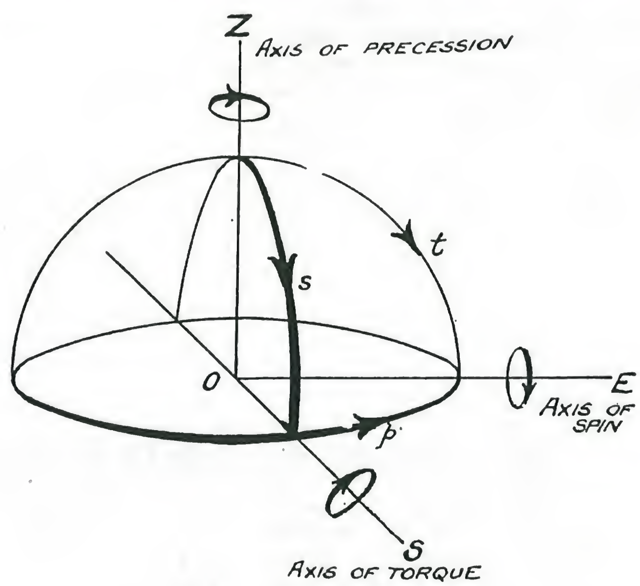


Fig. 62C

stitute a twisting movement or torque tending to twist the wheel about SO. The direction of this torque is right-handed as seen from S. Thus a torque tending to twist the wheel about the axis ON, produces a precession in the direction of a right-handed screw about the axis OZ (Fig. 62E).

Such a torque could be provided by a weight applied to the E end of

the gyro axle. This would cause the gyro to precess about an axis at right angles both to the spin axis and the torque axis.

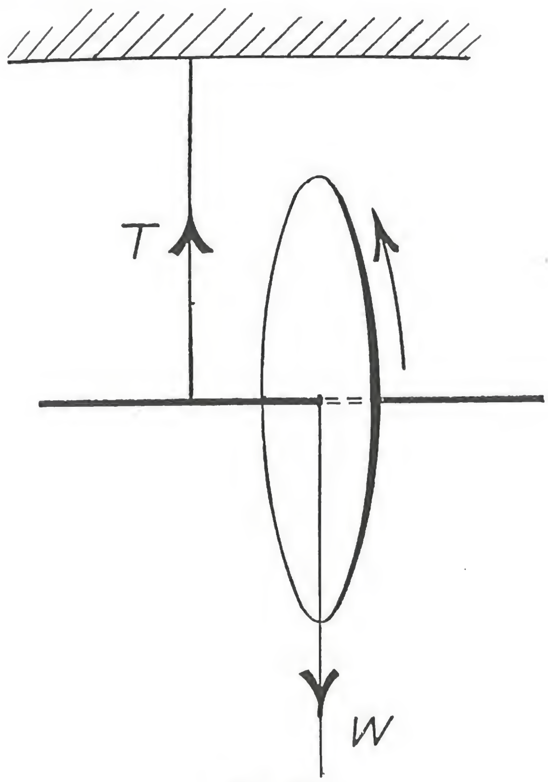


FIG. 62D

A similar effect can be observed if a cycle wheel is suspended by a cord attached to a point on the axle. So long as the wheel is at rest it cannot

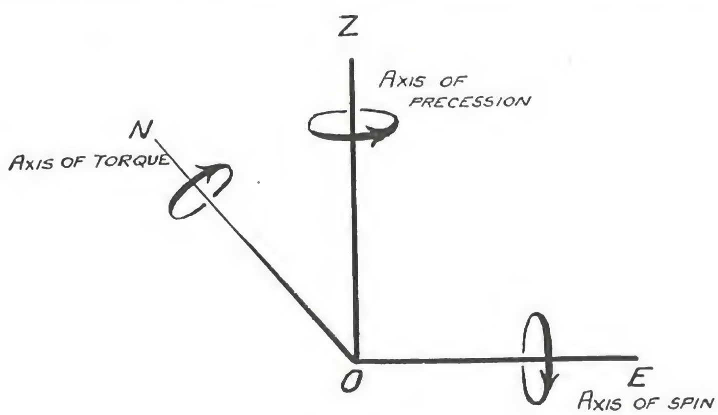


FIG. 62E

maintain the position shown in Fig. 62D without additional support. If it is made to revolve, it is capable of maintaining its plane of revolution

vertical. It will be seen, however, that the axle revolves slowly in azimuth, namely in a horizontal plane. This is the precessional motion due to the action of the torque produced by the equal forces, T the tension in the cord and W the weight of the wheel.

The three axes of spin, torque, and precession are mutually at right angles and the directions of rotation are those of right-handed screws along the axes OE, ON, and OZ (Fig. 62E).

To sum up: The direction of the axis of a free gyro remains fixed in space provided the forces acting do not produce a torque about its centre of gravity. If such a torque is produced and its axis is not parallel to the spin axis of the gyro, the effect of the torque is to cause a change in the direction of the gyro axis. The resulting angular motion of the gyro axis is called **Precession.**

It should be noted that if at a point O the axes of spin and torque are set out at right angles as at OE and ON, the axis of precession OZ is at right angles to both, and the direction of the precessional turn is such as to rotate the axis of spin towards the torque axis by the shortest route.

*APPENDIX VIII

HASLER TEL INDICATOR AND RECORDER

THE mechanism of the Tel Indicator and Recorder is very ingenious, and the reader who has an opportunity of examining the action when the cover is removed should be able to follow the sequence of operations with the assistance of the following notes.

The flexible shaft is connected at one end to some convenient rotating part of the engine (usually the camshaft drive); and at the other end to the vertical spindle extending through the bottom casing. At its upper end the spindle 1 carries a bevel-wheel, which engages the bevel wheels 2 and 3 mounted on the shaft 4 (Fig. 64A). This shaft rotates in one direction only, irrespective of the direction of rotation of the vertical spindle, the wheels 2 and 3 being connected to the shaft by keys and springs forming a ratchet drive. The shaft 4 drives the spindle *I I* by suitable gearing. On the spindle *I I* are fixed three segments (k_1), having on one side ratchet teeth, which can engage—or clear—corresponding teeth on three loose discs (k). The arrangement constitutes a set of three positive-drive clutches.

The spindle *I I* is shown with the associated mechanism in greater detail in Fig. 64B. The pinion r is attached to the loose disc k and both can be moved along the spindle by the lever H, which is actuated by a conical-faced cam mounted on the spindle I, driven at constant speed by clock-escapement mechanism. There are three such cams in the spindle I, one for each of the three clutches. Each cam has two sets of notches; formed at different radii as shown in Fig. 64C. The cams are positioned on the spindle I so that the notches on any one cam are displaced by 60° in relation to those on the other cams. As the spindle I rotates, the roller A, at the end of the lever H, under the action of a spring (which keeps it in contact with the cam) slips into one of the notches, thus engaging the two parts of the corresponding clutch and causing the pinion r to drive the wheel Z, which rotates freely on the spindle *I I I*. As Z rotates, the projection m on its rim engages the stirrup U carrying the pointer P of the speed indicator. The pointer is thus carried round to an extent depending on the speed of shaft *I I*, and on the time the two components of the clutch are in engagement. The time of engagement is determined by the speed of shaft I and by the shape of the cam, and these are arranged so that the clutch is closed for exactly one second. Thus the pointer is rotated through an angle directly proportionate to the speed of rotation of the spindle *I I*, and therefore to the engine speed.

At the end of one second, the cam moves the lever H and the clutch is disengaged. The stirrup would then fly back to its original position under the action of a spring, but for the effect of a second lever H_1 (see Fig. 64B). A conical roller B on the upper end of this lever works against an inner face on the cam, in which there are two outer notches at right angles to those on the outer face of the cam. At the lower end of the lever a toothed block B_1 is mounted. At the end of the first second the clutch parts are released and the block B_1, actuated by the movement of the lever H_1, holds k (and therefore r, Z and U) stationary for another second, at the end of which time k is released and Z returns to its original position during the

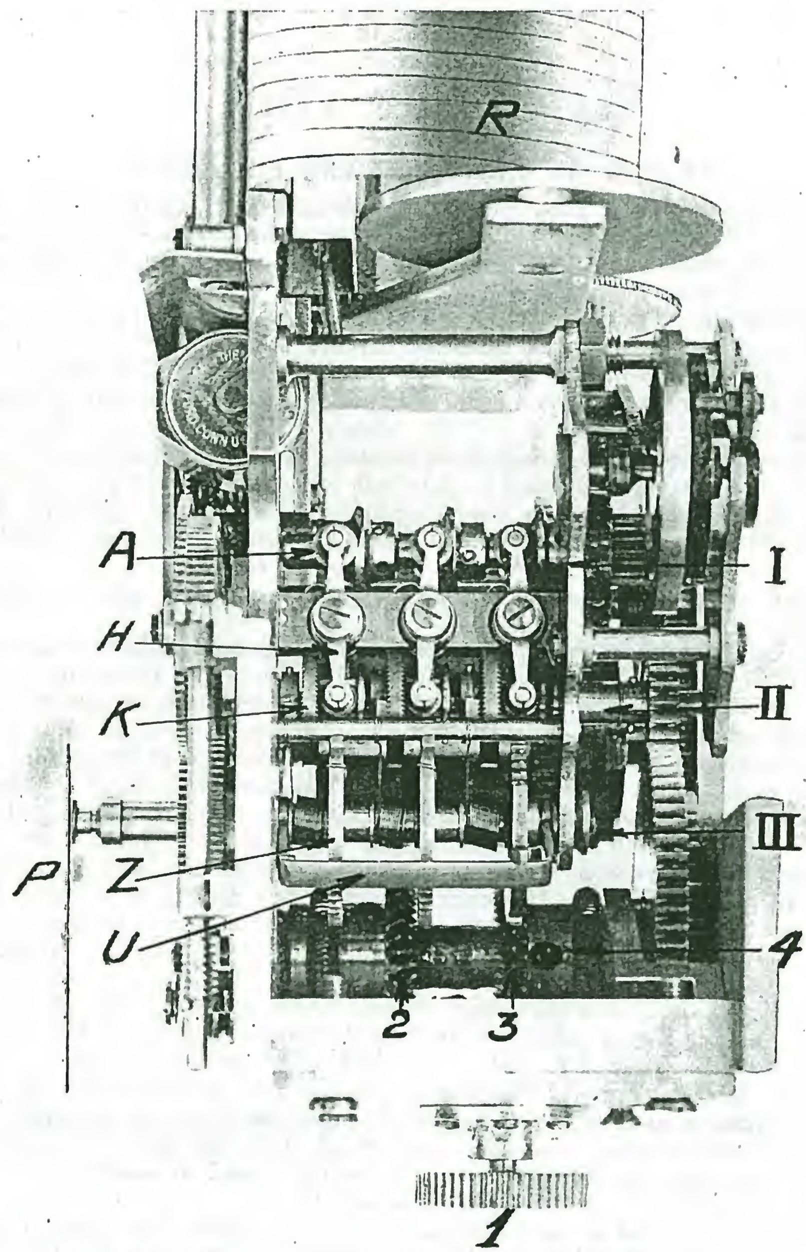


FIG. 63. HASLER TEL INDICATOR (CASE AND CLOCK REMOVED)

third second. The stirrup U is common to all the three sets of cams and levers, clutches, and gearing. One set only is shown in Fig. 64B.

The cycle of operations is carried on by all three sets of cams, with a time displacement of one second. Each complete cycle occupies three seconds, and thus the instrument indicates each second the mean speed of the preceding second.

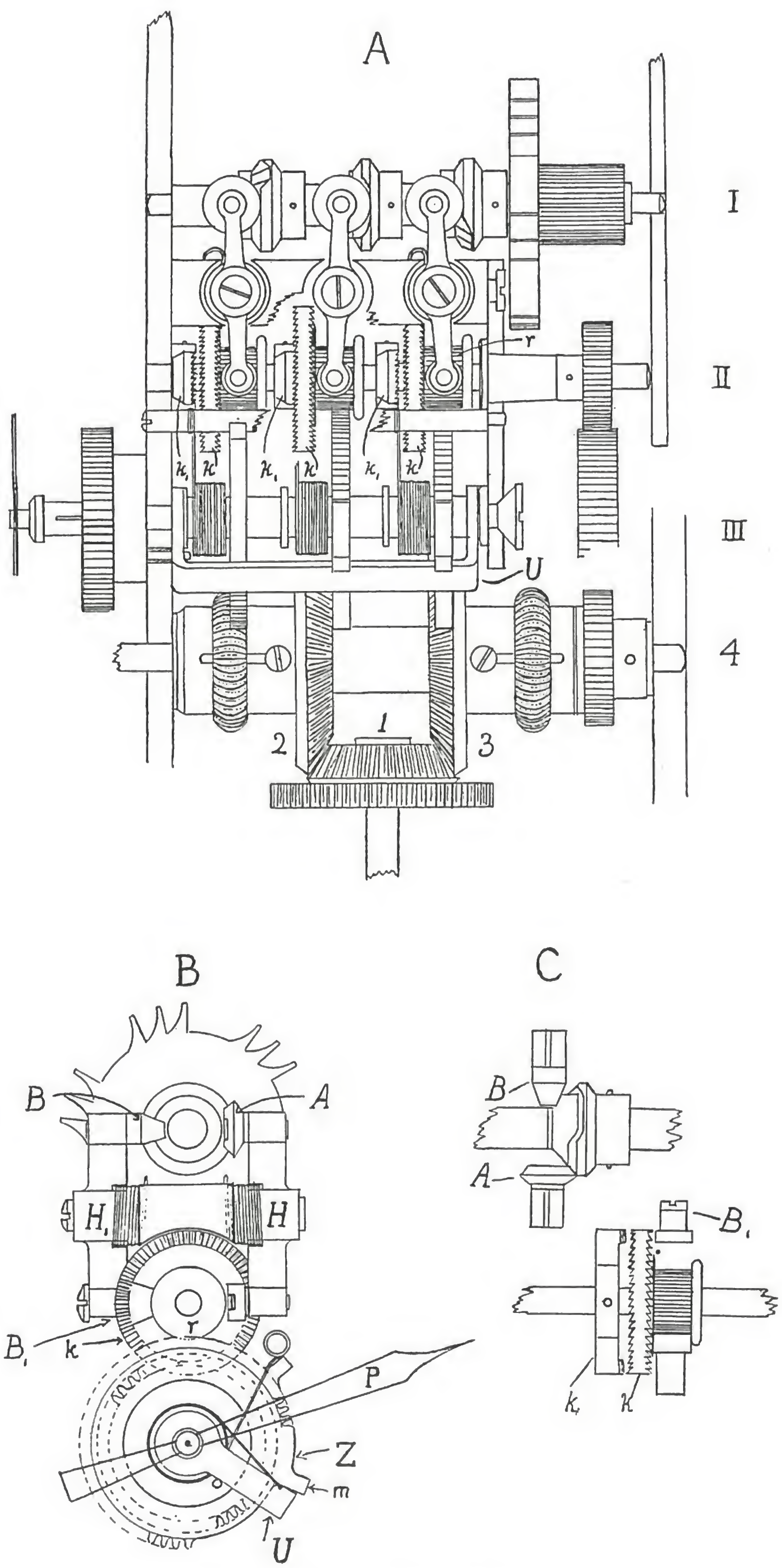


Fig. 64. Tel Indicator

The clockwork mechanism for driving the camshaft is wound automatically from the driving spindle approximately every two minutes. The winding gear is automatically disconnected when the spring is fully wound so that over-winding is prevented. The chart drums are driven by the same clockwork mechanism as the camshaft, the stylus being actuated by gears and rack mechanism from the spindle of the pointer.

The eight-day clock is a separate unit and is wound by hand. It actuates a second stylus, moving up and down vertically on the chart *R*, giving a

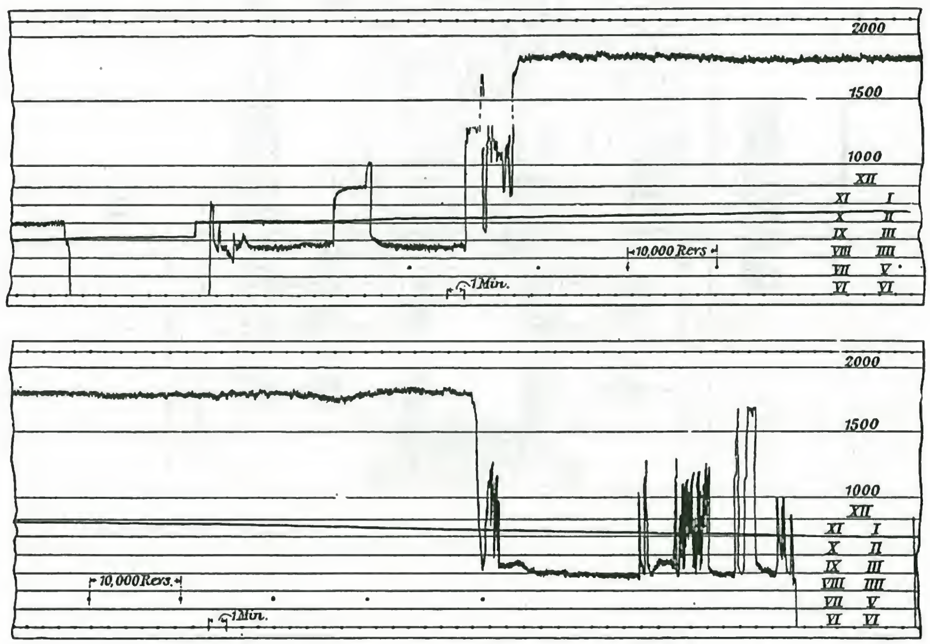


FIG. 65. PORTION OF CHART RECORD OF TEL INDICATOR

time record in the form of a line inclined upwards from 6 to 12 o'clock, and downwards from 12 to 6 o'clock. When the engine is not running, the paper is stationary and the time line is vertical as shown on the left-hand side of Fig. 65, indicating the fact that the engine was stationary for nearly half-an-hour before commencement of the flight. The small knurled knob near the right-hand corner is provided for setting the clock hands. The knob on the other side sets the counter to zero. The setting of the stylus is very critical, a small fraction ($\frac{1}{8}$th) of a turn making the difference between a faint record and a torn chart. After adjustment, the stylus bar should be removed and the setting locked by means of shellac varnish.

The drum carries a length of paper sufficient for a record of 100 hours' flight. Portions of a chart record reproduced in Fig. 65 show the conditions of commencement and finish of a flight.

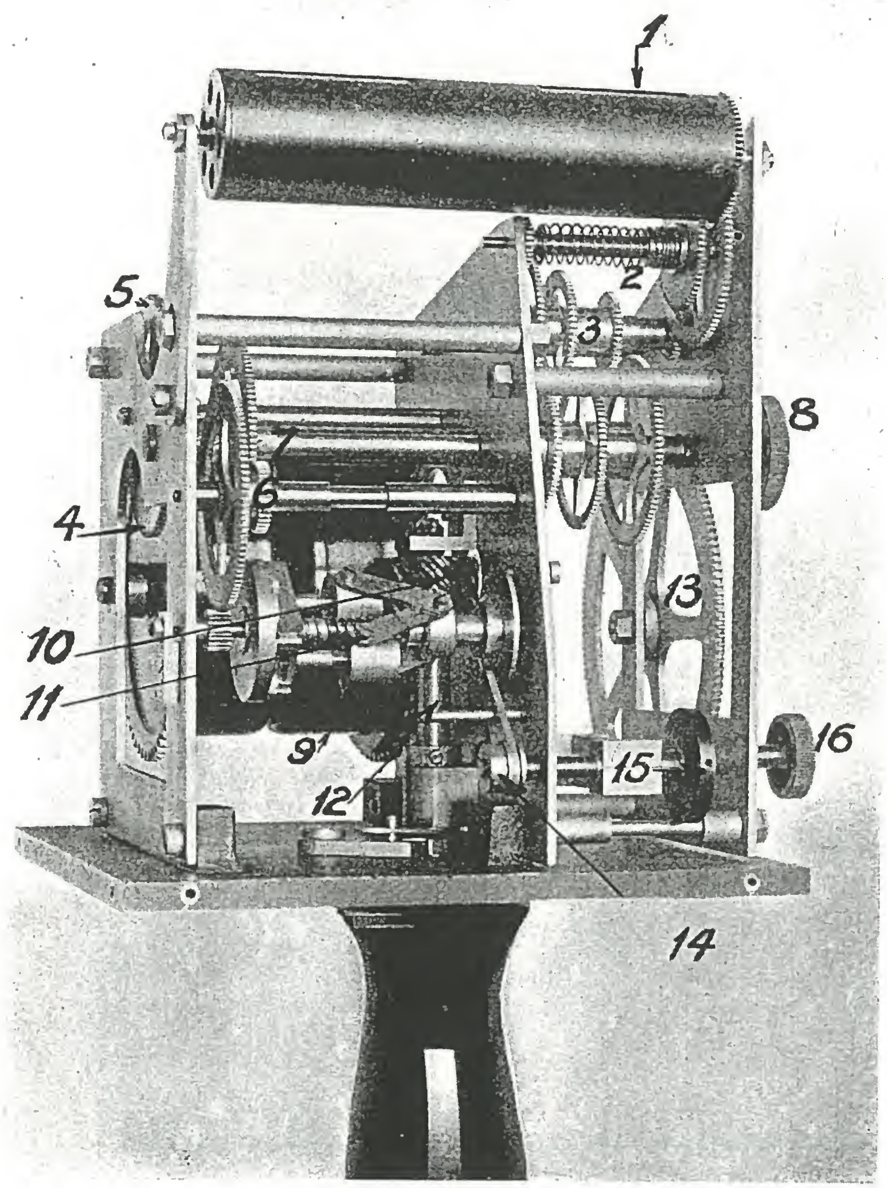


FIG. 66. ASHDOWN ROTOSCOPE ("A" TYPE) (CASE REMOVED)

1. Sight gear (shutter)
2. Equalizer
3. 5-speed gear change
4. First gear
5. Second gear
6. Third gear
7. Main spindle
8. Primary
9. Main spring unit
10. Winder gear
11. Balancing governor
12. Winding shaft
13. Index gear
14. Governor control
15. Regulator
16. Governor head

APPENDIX IX

THE ASHDOWN ROTOSCOPE

The Ashdown Rotoscope is an instrument designed primarily for measurements of speeds of rotation. It can also be made to provide a "slow-motion" view of rapidly rotating objects, particularly useful in the study of moving machinery.

The object under study is viewed through a shutter, which is caused to open and close so as to give glimpses of the object at regular intervals. The shutter is actuated by a powerful spring-driven mechanism, and its speed is controlled by a 5-speed gearbox, giving the coarse adjustment of speed, with a fine-speed control by means of a balancing governor.

At the right-hand side of the box is a milled head (called the primary) marked with a red spot. This head operates the 5-speed gearbox by drawing out the sleeve to the required position *A*, *B*, *C*, *D*, or *E* marked on the sleeve, the ratios being 1, 2, 4, 8, and 16 to 1 respectively. Since for every revolution of the shutter one has two views of the object, these ratios must be again doubled.

An example of the rotoscope settings is given in the table (p. 111).

The smaller of the milled heads at the side of the case operates the governor, by means of which the primary can be set to run uniformly at any speed between 50 and 125 r.p.m., indicated by the figure seen in the aperture at the side of the instrument. The speed of the shutter is given by this primary speed multiplied by the gear ratio.

An unknown speed is determined by systematic alterations of the shutter-speed by means of the controller, until a clear stationary view is obtained. This requires a little practice, and full details, with tables to assist the observer, are given in the booklet provided with the instrument. The general principle of the "stationary" or "stroboscopic" view is explained in the chapter on Engine Speed Indicators (see p. 7).

Care is necessary when manipulating the gear setting to ensure that the gear wheels are properly in mesh, namely when the letter *A*, *B*, *C*, *D*, or *E* appears just clear of the side of the case. The gears should be "felt into mesh" by slightly turning the primary milled head to and fro.

If the shutter-speed is set slightly lower than the speed of the object, the latter appears to be in "slow-motion," useful for close study of moving parts.

The "C" type Ashdown Rotoscope has a speed range of from 800 to 6,000 per minute, and the speed is read directly from the scales.

Checking and Adjusting the Ashdown Rotoscope

A simple method of checking the Rotoscope is provided by a synchronous electric motor operated from the 50 cycle A.C. lighting mains. A motor designed to run at 1,500 r.p.m. will be found convenient, and the speed will be kept reasonably constant by the controlled frequency of the mains supply. To the motor shaft is attached a small white disc with a black spot painted near the rim. Suppose the spot rotates in a clockwise direction at 1,500 r.p.m. when the motor is running, it should appear stationary when viewed through the rotoscope set for 1,500 r.p.m. If the spot appears to rotate slowly in an anti-clockwise direction the shutter

of the rotoscope is rotating too fast. If the spot appears to rotate in a clockwise direction, the shutter is rotating too slowly. In each case the necessary adjustment can be made on the regulator.

When this adjustment has been made at 1,500 r.p.m., other shutter speeds can be checked as indicated in the following table. The settings apply to "A" type Rotoscope, for speeds up to 4,000 r.p.m.

ROTOSCOPE SETTING (Speed of Object 1,500 r.p.m.)

Gear	Primary speed	Shutter speed r.p.m.	Image appears
B	125	500	Single
C	93·75	750	Single
C	125	1,000	Double
D	93·75	1,500	Single
D	125	2,000	Quadruple
E	93·75	3,000	Double

The reader will find it a useful exercise to think out the reason for the appearance of the image given in the last column, as well as to verify the following formulae connecting N the frequency of the rotoscope shutter, and x the number of spots visible.

$$(a)\quad x - \text{odd}\,;\ N = \frac{1500}{1 + nx},\quad \frac{1500\,.\,x}{2 + nx},\quad \frac{1500\,.\,x}{3 + nx},\ \ldots\ \frac{1500\,.\,x}{(n-1) + nx}.$$

$$(b)\quad x - \text{even}\,;\ N = \frac{1500}{2n + 1}$$

n being any number 0, 1, 2, 3, . . etc.

APPENDIX X

REPAIRS AND ADJUSTMENTS

The extent of instrument repairs and adjustments which may be attempted by ground engineers depends entirely upon facilities available in the way of equipment and tools and the manipulative skill of the individual. Certain adjustments, such as the resetting of the pointer positions on most instruments, can be carried out with the aid of the simplest of apparatus, and the minimum of apparatus installed will depend on the extent of the work which it is intended to carry out. Instruments embody very delicate mechanism, and it is extremely easy to upset completely the accuracy and performance by neglecting a few simple precautions. The ground engineer should, therefore, provide himself in the first place with such small tools as will facilitate careful handling. The following are the minimum requirements—

- 2 clock screwdrivers (two sizes).
- 3 watchmakers' screwdrivers (three sizes).
- 2 pairs tweezers—one pair at least to be kept free from magnetization.
- 2 or 3 pairs of small pliers of various types.
- Set of small files.
- 1 small bench vice with clamps.
- 1 bunsen burner and small soldering iron.
- 1 pointer remover.
- 1 hand vice.
- Watchmakers' brushes, cleaning rags, etc.

The necessity for cleanliness must be emphasized. Filings and dirt left in an instrument may have serious consequences.

Much information on the characteristics of the various instrument mechanisms can be obtained from actually dismantling and reassembling. The reader is strongly recommended to take every opportunity of building up his practical experience by obtaining any old or discarded or scrapped instrument and endeavouring, by a close study of its various parts, to dismantle, clean, readjust, and recalibrate it. It may not follow that the instrument is rendered serviceable by this means, but a training is built up in this way which will assist in the handling of instruments actually required for service.

Where replacements of parts are necessary, involving highly specialized machine tools, it is desirable that the instrument should be returned to a recognized repair depot rather than time should be wasted in attempts at repair which at best can only produce a makeshift. If, on the other hand, makers are willing to provide spare parts for their instruments, and these are fitted by ground engineers, recalibration and/or re-ranging are invariably necessary. The importance of allowing an instrument to settle down or "normalize" after assembly and before recalibration cannot be over emphasized.

Before individual types of instruments are dealt with, the following general remarks should be helpful in enabling considerable instrument work to be undertaken by anyone with average skill.

In the first place, the ground engineer should provide himself with a bench which should be conveniently situated close to his test apparatus and in a good light. The bench should be covered with linoleum or oil-cloth, and should be kept free from dirt and filings. Suitable racks and holders should be provided for the orderly accommodation of tools, etc.

In dismantling an instrument, it is always advisable to study the mechanism and its adjustments before work is commenced. This precaution often saves time on reassembly. A small tray for screws and very small parts is necessary, and wide-mouthed glass jars with lids will be found useful. A dish of petrol should be at hand for the immersion of fouled and dirty parts. During dismantling a close watch should be kept for worn and strained parts, so that these may be replaced if necessary. The lubrication of instruments is a subject of special study, since the functioning of certain instruments is adversely affected at low temperature by the presence of oil where it is not intended that any should be applied. Gearboxes and ball-races of engine speed indicators should be greased with a special grease, but on no account should oil be applied to the surface of the centre spindle. This will inevitably result in excessive friction at low temperature. The altimeter should not be lubricated, but on the other hand special watch oil is very sparingly applied to jewel holes in watches and to the mainsprings. Therefore all parts, after immersing and washing in petrol, should be well brushed with a watchmaker's brush which has been kept free from grease and dirt.

Pivot and spindle holes should be cleaned with a piece of sharpened pegwood or wood with little grain.

Glasses. The face glass of an instrument is the part that most frequently requires replacement. The glass is usually fitted to an instrument in one of the three following ways—

(*a*) The glass is held in position beneath a screw-on bezel.

(*b*) A bevelled-edge glass is snapped into a recess in the bezel as in watches, altimeters, and some engine speed indicators.

(*c*) The glass is retained by a spring ring snapped in place above it.

In every case the fitting of a glass should be carried out so that it is tight under vibration and not liable to fall out. If glasses are fitted as (*a*) the bezel must be tightened down on to the glass, paper washers being used if the new glass is thinner than the discarded old one. It is a good plan to accumulate a stock of instrument glasses of various sizes.

Pointers. It frequently happens that instrument pointers become loose or detached from their spindles in service. Although these may seem to have been replaced securely, they may work loose again subsequently. Pointer spindles are invariably tapered, in which case the pointer collet must be reamed out to suit its particular spindle, otherwise the area of contact between the collet and spindle is insufficient for security. If this point is given particular attention failures are unlikely to occur.

When instruments are reading inaccurately, the errors are often found to be uniformly high or low when measured in terms of angular deflection of the pointer. A resetting of the pointer, therefore, would render the instrument quite serviceable. This operation may be performed in the following simple manner—

(*a*) Remove the instrument bezel and glass. In most cases the bezel is easily removed. It may be either the screw-on type or (as in the case of some of the older types of pressure gauges and engine speed indicators) attached by three or more screws to the case. In some of the earlier "Smith" type air speed indicators the bezel with a spun-in glass is screwed into the main casting and cemented. In this case it will be

necessary to apply heat in order to soften the cement. This is best performed by the use of a special bezel removing tool in the form of a ring-wrench which can be gently warmed up and clamped on to the bezel for unscrewing, whilst the instrument case is firmly held either by a second operator or in suitable wood block held in a large vice.

(*b*) Remove the pointer from its spindle, taking care that the spindle is not bent during the process. Most pointers are push-fits on the spindle, and should be withdrawn with a pointer remover—shown in Fig. 67. This is accomplished by placing the recess in the bottom plate of the remover under the pointer collet flange, and screwing down the screw on to the end of the pointer spindle so as to force the collet from the spindle.

Great care should be taken with luminized pointers since the luminous compound is easily dislodged.

(*c*) Connect the instrument with the standard test instrument and operate the apparatus until the standard reads somewhere about the middle of the scale of the instrument. Tap the instrument so as to overcome the friction and replace the pointer so as to read accurately at this point.

Readings should then be taken throughout the range of the instrument and, when it is confirmed that the pointer is accurately set, it should be lightly but securely tapped on.

POINTER REMOVER

FIG. 67

During the resetting of a pointer, it is important to note whether the dial is adequately secured from moving relative to the instrument case. Unless the dial is secured from rotating, inaccuracies are inevitable.

Painting of Metal Cases. During the overhaul of an instrument it is frequently necessary to repaint its metal case. This is important, since painting is a protective measure against corrosion. Before repainting, the case must be thoroughly cleaned of all old paint, grease, and oil. In an aluminium case this is best done by scraping and papering, and afterwards thoroughly cleaning in petrol. The surface must be free from grease, or flaking of the paint will occur. The case should preferably be spray-painted with a cellulose matt-black lacquer, but if no spraying plant is available it can be brush-painted with any suitable proprietary black enamel or lacquer.

Worn Bearing Holes. Play in the movement of an instrument may be frequently traced to worn bearing holes, and, provided that the wear is only slight, the hole may be closed and re-broached to size, as a temporary measure only. This is effected by the use of a round-ended punch, which should be applied to the surface of the plate round the hole at equal intervals so as to close in the hole to slightly less than is finally required, that is to say, the spindle which the hole normally takes should just fail to enter the hole. The hole should then be carefully broached to the correct size.

Hairsprings. Practically every instrument is fitted with a hairspring, the function of which is to take up backlash in gears, etc. Hairspring collets are usually mounted on the pointer spindles above the pinion, which engages the toothed segment of the movement. Unless a hairspring is correctly fitted and shaped, there is a danger of the spring buckling when under tension, with the result that it is liable to become entangled in the gearing. Most pressure gauges, air speed indicators,

and thermometers are provided with a hairspring guard which prevents this happening.

Hairsprings should, therefore, lie flat, with their coils equally spaced when not under tension.

It may be necessary to fit a new hairspring to an instrument. It is generally possible to obtain hairsprings already fitted to suitable collets, but if it is desired to fit a new hairspring to an existing collet, considerable care is necessary. When the old collet is removed from its spindle and the old spring detached from it, the new spring must be bent at its inner coil, so that when it is pinned the collet will lie in the centre. In order to pin the spring to the collet successfully, care must be taken to see that the pin, together with the spring end, fit the hole in the collet properly, and that the pin is of such a length as not to project unduly from the hole. In pinning the spring it is necessary to have some means of holding the collet tightly. It may be held on a tapered broach or similar tool.

Most instruments are fitted with phosphor-bronze hairsprings on account of the non-rusting and non-magnetic properties of this metal, and it is not desirable to refit steel springs when making replacements, but to take the opportunity to fit ones of phosphor-bronze.

The above remarks do not, of course, refer to the mainsprings of watches, the refitting of which calls for considerable skill and training. In fact, the repair of watches, generally, is best left to a qualified watchmaker.

The adjustments and modifications considered above are generally of a minor character, and are applicable to instruments in general. The following notes refer to certain individual instruments, and deal with repairs and modifications of a major nature. These should not be attempted except by a skilled instrument maker.

Altimeters. The most common cause of failure in an altimeter is the breakage of the fine chain connecting the lever to the arbor on the pointer spindle. This chain is anchored by means of small pins to the pointer spindle arbor at one end, and to a small metal strip at the other; it is usually supplied in lengths by manufacturers, and from these the desired length for an instrument can be cut. Since the smooth working of an altimeter depends to a very large extent on the freedom of the links of the chain, it is not sufficient to refit a chain without previous "suppling." This is done in the following manner.

A polished metal pin of approximately $\frac{1}{16}$ in. diameter is either held horizontally in a vice or driven into the edge of the bench. The chain is slightly oiled, and with one turn round the pin is drawn slowly backwards and forwards at right angles to the pin for two or three minutes. It is then thoroughly cleaned in petrol and dried off. The operation may then be repeated, once or twice only, on the pin in a dry state. If when the chain is fitted there is any tendency towards friction in the links, and the hairspring will not take up the chain smoothly, it has been insufficiently "suppled."

Other faults likely to be found in altimeters are—

(*a*) Diaphragm damaged or leaking.
(*b*) Deterioration of mainspring.
(*c*) Dial zero setting pinion damaged, e.g. stripped teeth.

The pinion can, of course, be replaced without altering the instrument adjustment, but care should be taken to ensure that the dial setting works smoothly, and neither too easily nor too stiffly. It is not desirable to attempt to refit diaphragms or mainsprings, but if this is carried out the

instrument must be allowed ample time to settle down after assembly and before final regulation and test. The diaphragm spring assembly must be levelled up by means of the carriage adjusting screw and roughly ranged. Final and fine adjustments are carried out by means of the regulator screw on the pivoted spindle. In re-assembling an altimeter, special attention should be given to the following points—

1. Steel chain should be supple and work smoothly.
2. Regulator spindle and pointer spindle pivots should be suitably burnished.
3. Transmission link holes must not be elongated or enlarged through wear.
4. Dial adjustment must work smoothly.
5. Pointer must rotate in a plane parallel to the dial.
6. No oil or lubricant to be applied anywhere.
7. The hairspring must be free from corrosion and distortion, and be tight on its spindle.

Boost Gauges. Deterioration of the synthetic rubber washer, which helps to make the joint between the glass and the case airtight, is a frequent cause of failure. This can usually be cured, for a time at any rate, by tightening the bezel. The remarks on the repair and adjustment of the altimeter apply to the boost gauge.

Air Speed Indicator. The principal trouble likely to occur with air speed indicators is the development of leaks. These leaks may occur at the bezel or may be due to strain on the joints or the diaphragm. In the latter case, when a metal diaphragm is fitted, this strain is accompanied by a marked displacement of the pointer from its zero position when no pressure is applied to the instrument.

A bezel leak is best cured by removing the bezel, thoroughly cleaning the threads, and refitting with a new rubber ring before screwing down tightly. In the case of the screwed-in and cemented bezel, a leak may be stopped, as a temporary measure, by the application of shellac. Since a leak at the bezel affects the static side of the indicator only, it is not found seriously to interfere with accuracy of indications, provided it does not exceed, say, 10 m.p.h. in 10 sec. when pressure is applied equivalent to 160 m.p.h., and the static nipple "stopped off." A leak on the static side may become serious, however, if the static side of the indicator is connected up to the altimeter in the cockpit, owing to pressure changes. Most specifications, however, permit a leak not exceeding 15 m.p.h. in 10 secs., when pressure equivalent to 150 m.p.h. is applied and the static nipple "stopped off."

A distorted diaphragm due to excessive pressure does not normally arise in service, but accidental overloading may occur during installation or testing, and distortion may not be apparent until the indicator is tested for accuracy, when it will be found to read high. The total diaphragm movement may be affected so that pointer resetting does not effect a remedy. In this case replacement of the diaphragm is necessary, and a new one should be obtained from the manufacturers of the instrument. Absolute uniformity in physical properties of metal diaphragms is extremely difficult to obtain in manufacture, and to range an instrument with a new diaphragm to agree with the old dial scale markings is frequently outside the range of adjustment of the mechanism. The dial will therefore have to be re-divided. As in the case of the altimeter, the instrument must be allowed to settle down by ageing after assembly and before re-calibration.

The mechanism should be free from friction or undue wear, and the hairspring symmetrical and free from corrosion.

Pressure Gauges. Pressure gauges, like air speed indicators, are occasionally subject to overload pressures which affect the diaphragm or Bourdon tube. The failure of a pressure gauge is often an indication that the Bourdon tube has been badly strained or burst. Traces of oil on the dial or glass also point to a leaking tube. Most pressure gauges are designed to withstand overloads up to 100 per cent of their scale range, so that a burst tube is either accidental or a sign that ageing has taken place.

Bourdon tubes are made, by special processes, of phosphor-bronze or other elastic metal of thickness and section appropriate to the range of the gauge. They are soft-soldered into the casting at the base, which also forms a support for the mechanism and is provided with a connecting hole to the threaded union. The other end of the Bourdon tube is sealed by means of a light cap (soldered in position) bearing a connexion for the linkwork of the mechanism. In fitting a new Bourdon tube to a gauge, a considerable amount of soldering is necessary, and there is a danger that overheating may affect the elastic properties of the metal. It is therefore essential that soldering "irons" of the correct size and shape be used to localize the applied heat. Care is also necessary to avoid either the whole or partial blockage of the connecting hole with solder. Under vibration, loose pieces of solder left inside the tube are liable to be shaken down into the hole and cause a stoppage in service.

A pressure gauge which has been fitted with a new Bourdon tube can, possibly, be readjusted to agree with the original dial, provided that the new tube is of such a thickness of metal and cross-section as to give approximately the same pressure-deflection characteristics as the old one. Small adjustments for ranging are possible by carefully bending the links to increase or decrease the leverage of the quadrant.

In reassembling a gauge, special care must be given to ensure freedom from friction or corrosion in the mechanism, and to see that none of the bearing holes are worn. The hairspring must be fitted symmetrically, and so as to obviate the danger of the spring buckling under tension and fouling the mechanism. A maximum stop is generally fitted. This operates on the Bourdon tube, when the pressure is just greater than the highest scale reading. The stop must be quite definite in its operation.

Engine Speed Indicators. Defects in engine speed indicators are very often indicated by unsteady readings or extreme stickiness of the mechanism. These are mainly due to worn parts or the ingress of oil respectively. Before definitely condemning an indicator, however, it is advisable to inspect carefully the flexible drive, since an old drive, which has been coiled or bent for a considerable period, invariably develops a "whip" which is responsible for unsteadiness of indications in the indicator. In fitting a new inner cable to a drive, the process of soldering the squared connectors, as detailed on page 5, should be followed.

In dismantling an instrument for overhaul, the general precautions already detailed should be carefully observed. The whole mechanism should be thoroughly cleaned and washed in petrol, ball-races should be freed and examined, and the reduction gear overhauled and greased with a suitable non-freezing grease. End adjustment of the main spindle must be carefully made.

The polished portion of the main spindle on which the sliding muff operates must be perfectly clean, and in no circumstances should any

lubricant be applied to this surface. Stickiness will result if this is not observed.

After overhaul, tests should be carried out for the following points and adjustments made, if necessary, for the following—

(*a*) *Inaccurate Ranging.* This may be due to the tension on the governor spring.

(*b*) *Differences in Readings with Clockwise and Anti-clockwise Directions of Rotation.* This is generally found to be caused by the quadrant connecting lever taking up a different position in the sliding muff on reversal of rotation.

(*c*) *Unsteadiness of Readings.* Unsteadiness is due to a number of causes, e.g. worn parts, muff not running truly, unsteadiness in gears, clearance adjustments, etc.

(*d*) *Friction* and too much difference between readings with increasing and decreasing speeds, due to tightness of moving parts or the presence of oil where it is not required.

Finally, in the assembly of all types of instruments, it is essential for all screws, nuts, etc., to be sufficiently tight to withstand vibration. In many types of instruments small screws and nuts are secured by the application of shellac.

APPENDIX XI

LIST OF CIVIL INSTRUMENT SPECIFICATIONS

THE following Civil Instrument Specifications were issued in June, 1934, with Amendment List No. 39 to Air Publication No.1208, the Airworthiness Handbook for Civil Aircraft.

1. Altimeters.
2. Air Speed Indicators.
3. Pressure Head for use with Air Speed Indicators.
4. Engine Speed Indicators.
5. Pressure Gauges for Oil and Fuel Systems.
6. Oil Temperature Thermometers.
7. Radiator Temperature Thermometers.
8. Turn Indicator.
9. Pilot's Magnetic Compass.

Note. No. 4 was cancelled by Amendment List 46 dated Feb., 1936, and 4A printed on page 125, substituted.

These specifications have recently been reissued under the general title of **Air Ministry Civil Specifications** and should now be referred to as C.S. No. 1, etc. The new issues are substantially the same as the previous issues which appear on the following pages, with the exception than an additional clause requires the instruments to be marked with the maker's name and serial number in a position readily readable when the instrument is installed in an aeroplane. It is also recommended that instruments be marked with the distinguishing number of the specification against which it has been certified, e.g. C.S. No. 4a.

Alterations and additions to these specifications may be made from time to time. The most recent issues can be obtained from H.M. Stationery Office, Kingsway, London, W.C. 2.

C.I.S. No. 1

AIR MINISTRY

Civil Instrument Specification No. 1

Altimeters

(Civil instrument specifications lay down the minimum requirements necessary for the approval of instruments and equipment required to be carried on civil aircraft under the Air Navigation Directions.)

General Construction. 1. The instrument shall be so proportioned and constructed that the vibrations experienced on an aircraft do not seriously affect its readings, impair its accuracy, or cause undue wear. All pins, screws, nuts, etc., shall be secure against working loose under vibration.

Method of testing and permissible errors for new and re-conditioned instruments. 2. (i) (*a*) The instrument will be tested with the dial upright in a vertical plane at room temperature (10° C. to 20° C.).

(*b*) The instrument will be lightly tapped before taking readings.

(*c*) The errors with pressure decreasing and increasing will be found from one continuous test, the pressure being varied at a rate equivalent to 1,000 ft. per minute and being kept constant for one minute at the pressure corresponding to the maximum range of the particular instrument,

1		2	3	4
Barometer inches		Height in feet	Permissible Errors 0–20,000 feet range	
Iso.	I.C.A.N.		Up	Down
29·99	29·99	0	0	+ 150
28·91	28·93	1,000	– 40	+ 150
27·87	27·89	2,000		+ 150
26·86	26·88	3,000	– 60	+ 150
25·89	25·91	4,000		+ 200
24·95	24·96	5,000		+ 200
24·05	24·04	6,000	– 80	+ 250
23·18	23·15	7,000		+ 250
22·35	22·28	8,000		+ 300
21·54	21·44	9,000	– 100	+ 300
20·76	20·63	10,000		+ 300
20·01	19·84	11,000		+ 350
19·29	19·08	12,000		+ 350
18·59	18·34	13,000	– 150	+ 350
17·92	17·62	14,000		+ 350
17·27	16·93	15,000		+ 400
16·65	16·26	16,000		+ 400
16·05	15·61	17,000		+ 400
15·47	14·98	18,000	– 200	+ 400
14·91	14·37	19,000		+ 400
14·37	13·78	20,000		+ 400

(ii) (*a*) The instrument shall be so adjusted as to indicate the heights shown in column 2 of the table on page 119 at the barometric pressure shown in column 1 within the tolerances shown in the table (columns 3 and 4).

(*b*) The movement is to be compensated for temperature changes between $-5°$ C. and $+35°$ C.

(*c*) The difference in reading at any part of the scale due to a change of position of the instrument between normal and 90° therefrom must be such that the errors are still within the limits given in this sub-paragraph.

(*d*) The maximum difference between the readings at any one pressure with pressure increasing and decreasing is not to exceed 400 ft.

Method of testing and permissible errors on inspection in connection with renewal of C. of A. 3. (i) The tests on the instrument will normally be carried out at room temperature (10° C. to 20° C.) and with the instrument in flying position.

(ii) The permissible errors under these conditions shall not exceed double those permitted in paras. 2 (ii) (*a*) and (2) (ii) (*d*) above.

C.I.S. No. 2

AIR MINISTRY

Civil Instrument Specification No. 2

Air Speed Indicators

(Civil instrument specifications lay down the minimum requirements necessary for the approval of instruments and equipment required to be carried on civil aircraft under the Air Navigation Directions.)

General construction. 1. (i) The instrument shall be so proportioned and constructed that the vibrations experienced on an aircraft do not seriously affect its readings, impair its accuracy, or cause undue wear. All pins, screws, nuts, etc., shall be secure against working loose under vibration.

(ii) The instrument shall be capable of withstanding an overload pressure of $33\frac{1}{3}$ per cent in excess of the pressure equivalent to the maximum scale reading.

Method of testing and permissible errors for new and re-conditioned instruments. 2. (i) (*a*) The instrument will be tested with the dial upright and in a vertical plane at room temperature (10° C. to 20° C.), and the figures shown in the tables will be used to determine the air speed from the pressure difference.

(*b*) The instrument will be lightly tapped before taking readings.

(ii) (*a*) The calibration shall be according to either one or other of the following relations—

(1) $P = 0{\cdot}012504\ V^2\ (1 + 0{\cdot}43\ V^2 \times 10^{-6})$ where V is the air speed in miles per hour, and P is the pressure difference in mms. of water at 15° C.

(2) $P = 0{\cdot}016580\ V^2\ (1 + 0{\cdot}57\ V^2 \times 10^{-6})$ where V is the air speed in knots, and P is the pressure difference in mms. of water at 15° C.

(3) The pressure differences are as follows—

For Speed in Miles per Hour

Air Speed m.p.h.	Pressure Difference mms.	Air Speed m.p.h.	Pressure Difference mms.	Air Speed m.p.h.	Pressure Difference mms.
40	20·0	110	152·1	180	410·7
50	31·3	120	181·2	190	458·3
60	45·1	130	212·8	200	508·7
70	61·4	140	247·1	210	561·8
80	80·2	150	284·0	220	617·6
90	101·6	160	323·6	230	676·3
100	125·6	170	365·8	240	737·9

For Speed in Knots

Air Speed knots	Pressure Difference mms.	Air Speed knots	Pressure Difference mms.	Air Speed knots	Pressure Difference mms.
35	20·3	100	166·7	170	487·0
40	26·55	110	202·0	180	547·1
50	41·5	120	240·7	190	610·9
60	59·8	130	282·9	200	678·2
70	81·5	140	328·6	210	749·5
80	106·5	150	377·8		
90	134·9	160	430·6		

(*b*) *Ranging.* The instrument shall be so adjusted as to indicate at room temperature the air speeds at the pressure differences shown in the tables with a tolerance of $\pm$ 2 m.p.h. or knots as may be appropriate.

(*c*) The error at any temperature between $-5°$ C. and $+35°$ C. shall not exceed $\pm$ 3 m.p.h. or knots as may be appropriate ($\pm$ 5 below 40 m.p.h.).

(*d*) The difference of reading due to a change of position of the instrument between the normal and 90° therefrom must not exceed, at any point on the scale, 2 m.p.h. or knots as may be appropriate (above 40).

(*e*) The pressure and static chambers must be sufficiently free from leaks, both to each other and to the outer atmosphere so that when a pressure difference of approximately 280 mms. of water is applied, and then shut off, the pointer does not fall more than 15 m.p.h. or 13 knots in 10 seconds.

(*f*) The constriction in the static nipple shall not be less than $\frac{1}{16}$ in. in diameter.

Method of testing and permissible errors on inspection in connection with renewal of C. of A. 3. (i) The tests on the instrument will normally be carried out at room temperature (10° C. to 20° C.) and with the instrument in flying position.

(ii) The permissible error under these conditions shall not exceed 5 m.p.h. or knots as may be appropriate.

(iii) The permissible leakage shall not be greater than that specified in para. 2 (ii) (*e*) above.

C.I.S. No. 3

AIR MINISTRY

Civil Instrument Specification No. 3

Pressure Head for Use with Air Speed Indicators

(Civil instrument specifications lay down the minimum requirements necessary for the approval of instruments and equipment required to be carried on civil aircraft under the Air Navigation Directions.)

General construction. 1. (i) The pressure head shall be constructed in accordance with the drawings accompanying this specification, or other approved form.

(ii) There shall be no leaks on either the static or pressure pipes when tested under a pressure of 2 lb. per square inch.

Note. The Drawings are not reproduced.

C.I.S. No. 4A

AIR MINISTRY

Civil Instrument Specification No. 4a

Engine Speed Indicators

(Civil instrument specifications lay down the minimum requirements necessary for the approval of instruments and equipment required to be carried on civil aircraft under the Air Navigation Directions.)

General construction. 1. The instrument shall be so proportioned and constructed that the vibrations experienced on an aircraft do not seriously affect its readings, impair its accuracy, or cause undue wear. All pins, screws, nuts, etc., shall be secure against working loose under vibration.

2. *Electrical engine speed indicators. Compass interference.* When an electrical indicator is placed in any position within 10 in. from the nearest edge of the case to the nearest edge of a compass, the latter shall not deflect more than 2°. Any variation of current in the complete set shall not cause any deviation of the compass. For the purpose of the test a type 253 Compass may be used.

3. *Method of testing and permissible errors for new and reconditioned instruments.*

(i) The instrument is liable to be tested under any combination of the following circumstances—

- (*a*) With the dial vertical or horizontal.
- (*b*) With the whole or any part of the equipment at any temperature between $-5°$ C. and $+35°$ C.
- (*c*) With speed increasing or decreasing.
- (*d*) With the drive (or generator) running in either direction.
- (*e*) Before or after 150 hours' running.

(ii) The instrument will be lightly tapped before taking readings.

(iii) With the dial vertical and the instrument at room temperature the error shall not exceed $\pm$ 25 r.p.m.

(iv) Under no combination of circumstances as outlined in para. 3 (i) above shall the instrument be in error by more than 40 r.p.m.

(v) The instrument shall be capable of running for 300 hours without additional lubrication.

(vi) The errors quoted in sub-paras 3 (iii) and 3 (iv) refer to a range of 2,000 r.p.m. between minimum and maximum readings. For other ranges, the errors shall be altered *pro rata*, e.g. for a range of 500 to 3,500 r.p.m. the permissible errors quoted would be increased by 50 per cent.

Method of testing and permissible errors on inspection in connection with renewal of C. of A. 3. (i) The tests on the instrument will normally be carried out at room temperature (10° C. to 20° C.) and with the instrument in flying position.

(ii) The permissible errors under these conditions shall not exceed double those permitted under para. 3, sub-paras. (iii) and (iv) above.

C.I.S. No. 5

AIR MINISTRY

Civil Instrument Specification No. 5

Pressure Gauges for Oil and Fuel Systems

(Civil instrument specifications lay down the minimum requirements necessary for the approval of instruments and equipment required to be carried on civil aircraft under the Air Navigation Directions.)

General construction. 1. (i) The instrument shall be so proportioned and constructed that the vibrations experienced on an aircraft do not seriously affect its readings, impair its accuracy, or cause undue wear. All pins, screws, nuts, etc., shall be secure against working loose under vibration.

(ii) The overloading capacity of each instrument shall be 100 per cent, i.e. the maximum load shall be double the maximum scale reading.

Method of testing and permissible errors for new and reconditioned instruments. 2. (i) (*a*) The instrument will be tested with the dial upright in a vertical plane at room temperature (10° C. to 20° C.).

(*b*) The instrument will be lightly tapped before taking readings.

(ii) (*a*) The error at any point of the scale shall not exceed the amount stated in column 2 of the following table—

1	2	3	4
Range of Instrument	Type of Error		
	Ranging	Temperature	Cumulative
lb./sq. in.	lb./sq. in.	lb./sq. in.	lb./sq. in.
0–10	± 0·5	± 0·8	1·0
0–25	± 1·0	± 1·5	2·0
0–50	± 2·0	± 3·0	4·0
0–100	± 3·0	± 4·5	6·0
0–200	± 5·0	± 7·5	10·0

(*b*) The reading shall be taken both with increasing and decreasing pressure and the test for the whole range of the instrument shall occupy approximately 20 minutes.

(*c*) After application of the maximum load for a period of 5 minutes, the instrument must not show any alteration in calibration exceeding 50 per cent of the permissible calibration error. Any alteration must entirely disappear within 24 hours after removal of the pressure.

(*d*) In performing this test the operations should be carried out in the following sequence—

1. A normal full scale range check with both increasing and decreasing pressure.

2. Overload to the maximum pressure.
3. Take readings with decreasing pressure for comparison with tests prior to overload.

(iii) The error at any point of the scale at any temperature between $-5°$ C. and $+35°$ C. shall not exceed the amount stated in column 3 of the above table.

(iv) The difference in reading at any part of the scale due to change of position of the instrument between normal and 90° therefrom must be such that errors are still within the limit given in column 4 of the above table.

(v) The instrument may be submitted to a pressure equivalent to 75 per cent of the maximum scale reading for a period not exceeding 6 hours. The final readings must be such that the errors are still within the limits given in column 4 of the above table.

(vi) The total error resulting from the above causes taken together must not exceed the amount stated in column 4 of the above table.

Method of testing and permissible errors on inspection in connection with renewal of C. of A. 3. (i) The tests on the instrument will normally be carried out at room temperature (10° C. to 20° C.) and with the instrument in flying position.

(ii) The permissible error under these conditions shall not exceed twice the amount given in column 4 of the above table. The error at zero, however, shall in no case exceed $\pm$ 1 per cent of the full-scale reading of the gauge.

C.I.S. No. 6

AIR MINISTRY

Civil Instrument Specification No. 6

Oil Temperature Thermometers

(Civil instrument specifications lay down the minimum requirements necessary for the approval of instruments and equipment required to be carried on civil aircraft under the Air Navigation Directions.)

General construction. 1. The instrument shall be so proportioned and constructed that the vibrations experienced on an aircraft do not seriously affect its readings, impair its accuracy, or cause undue wear. All pins, screws, nuts, etc., shall be secure against working loose under vibration.

Method of testing and permissible errors for new and reconditioned instruments. 2. (i) (*a*) The instrument will be tested with the dial upright in a vertical plane.

(*b*) The instrument will be lightly tapped before taking readings.

(ii) (*a*) At no part of the scale on either a falling or a rising temperature shall the error in calibration exceed the limits $-1°$ C. to $+2°$ C.

(*b*) With the capillary and/or the gauge at any temperature between $-5°$ C. and $+35°$ C. the readings shall not differ by more than 2° C. from that with the capillary and/or the gauge at 15° C. The bulb temperature at which this test will normally be applied may vary from 0° C. to 20° C.

(*c*) The difference in reading at any part of the scale due to a change of position of the instrument between normal and 90° therefrom must be such that the errors are still within the limits given in this clause.

(*d*) Errors due to a difference in level between the bulb and the indicator shall not exceed 0·05° C. per foot of height.

(*e*) There shall be no appreciable error due to a change of external pressure down to 20 in. of mercury.

Method of testing and permissible errors on inspection in connection with renewal of C. of A. 3. (i) The tests on the instrument will normally be carried out at room temperature (10° C. to 20° C.) and with the instrument in flying position.

(ii) The permissible errors under these conditions shall not exceed double those specified in para. 2 (ii) (*a*) and (*b*) above.

Note. Vapour pressure transmitting types do not satisfy Clause (ii) (*e*) of this specification.

C.I.S. No. 7

AIR MINISTRY

Civil Instrument Specification No. 7

Radiator Temperature Thermometers

(Civil instrument specifications lay down the minimum requirements necessary for the approval of instruments and equipment required to be carried on civil aircraft under the Air Navigation Directions.)

General construction. 1. The instrument shall be so proportioned and constructed that the vibrations experienced on an aircraft do not seriously affect its readings, impair its accuracy, or cause undue wear. All pins, screws, nuts, etc., shall be secure against working loose under vibration.

Method of testing and permissible errors for new and reconditioned instruments. 2. (i) (*a*) The instrument will be tested with the dial upright and in a vertical plane.

(*b*) The instrument will be lightly tapped before taking readings.

(ii) (*a*) The error of calibration at any point shall not be negative or exceed + 2° C. at an atmospheric pressure approximately equivalent to 760 mms. of mercury.

(*b*) With the capillary and/or the gauge at any temperature between – 5° C. and + 35° C. the reading shall not differ by more than 2° C. from that with the capillary and/or the gauge at 15° C. The bulb temperature at which this test will normally be applied may vary from 55° C. to 73° C.

(*c*) The difference in reading at any part of the scale due to a change of position of the instrument between normal and 90° therefrom must be such that the errors are still within the limits given in this clause.

Method of testing and permissible errors on inspection in connection with renewal of C. of A. 3. (i) The tests on the instrument will normally be carried out at room temperature (10° C. to 20° C.) and with the instrument in flying position.

(ii) The permissible errors under these conditions shall not exceed double those specified in para. 2 (ii) (*a*) and (*b*) above.

C.I.S. No. 8

AIR MINISTRY

Civil Instrument Specification No. 8

Turn Indicator

(Civil instrument specifications lay down the minimum requirements necessary for the approval of instruments and equipment required to be carried on civil aircraft under the Air Navigation Directions.)

General construction. 1. (i) *Principle.* The instrument shall consist of a gyroscope, mounted in a horizontal gimbal ring which is pivoted about an axis normal to the plane of the dial and suitably damped. Angular movement of the gimbal ring against suitable spring or gravitational restraint shall be indicated by a pointer on the dial of the instrument. The gyroscope may be electrically or air driven. In the latter case, a venturi tube capable of giving the required air flow when fitted to the aircraft on which the instrument is to be used shall be supplied. The lateral component of apparent gravity shall be indicated on the dial of the instrument either by a pointer connected to an air damped pendulum, or a bubble type cross level. The instrument shall be so proportioned and constructed that the vibrations experienced on an aircraft do not seriously affect its readings, impair its accuracy, or cause undue wear. All pins, screws, nuts, pointers, etc., shall be secured against working loose under vibration.

(ii) *Rotor.* The rotor shall be balanced about its axis of spin.

(iii) *Sensitivity control.* In the case of a spring-controlled instrument, a suitable spring shall be attached to one end of the gimbal ring and at the other end to means whereby the spring tension may be varied to obtain the required sensitivity. This adjustment need not be operable from the outside of the case when mounted on the instrument board.

(iv) *Bearings.* Adjustable ball bearings shall be fitted to the gyro rotor and to the horizontal gimbal ring. The adjustment shall be locked in position when the required setting has been obtained.

(v) *Air filter.* In the case of air driven instruments, an efficient and readily detachable filter shall be fitted on the air inlet leading to the jet, so designed as to prevent the ingress of dust.

Method of testing and permissible errors for new and reconditioned instruments. 2. (i) *General.* (*a*) Unless otherwise specified the instrument shall be tested in the normal position at room temperature (10° C. to 20° C.). The normal position is that in which the dial is upright and in a vertical plane.

(*b*) Light tapping of the instrument case is permissible during test.

(ii) *Sensitivity.* (*a*) The sensitivity of the instrument at room temperature (10° C. to 20° C.) shall be such that a pointer deflection of 0·1 in. is obtained for a rate of turn of 45° per minute $\pm$ 20 per cent.

(*b*) The instrument shall be so adjusted that the scales are reasonably linear.

(*c*) At any temperature, other than room temperature, between

$-5°$ C. and $+35°$ C. the tolerance on the rate of turn to produce a pointer deflection of 0·1 in. shall be 10 per cent on the actual calibration at room temperature.

(iii) *Venturi*. In the case of air driven instruments, the venturi shall be designed to give the above sensitivity at a speed of the venturi through the air of 100 m.p.h. For the information of manufacturers, the suction likely to be expected from a single venturi of the usual type employed for turn indicators is about 1·5 in. of mercury at this speed. It is to be noted that this figure is dependent upon the size of the jet in the turn indicator.

(iv) *Gyro*. With the gyro rotor spinning or stationary there shall be no apparent deflection of the pointer from zero when the indicator is rotated about an axis normal to the plane of the dial.

(v) *Inclinometer unit*. (*a*) The range of this unit shall be $\pm 20°$.

(*b*) Within the temperature range of $-5°$ C. to $+35°$ C. the instrument shall be so adjusted as to indicate the inclination with a tolerance of ± 5 per cent of the total range.

(*c*) In the case of the bubble type inclinometers the liquid shall not separate, freeze or become so viscous as to cause sluggishness of the bubble movement at a higher temperature than $-5°$ C. The consistency shall be such that the bubble, while not easily broken up under vibration, will rapidly coalesce say within 2 seconds approximately of the cessation of an excessive vibration.

(vi) *Damping*. (*a*) The damping of the turn indicator unit and the pendulum inclinometer unit shall be such that, after any given displacement, the pointer shall pass beyond the zero mark by an amount not exceeding one quarter of the initial displacement. This test shall be carried out at room temperature.

(*b*) The damping of the bubble type inclinometer unit shall be such that from a full scale displacement the bubble comes to rest not more than 4 seconds after the instrument has been returned to the zero position. This test shall be carried out at room temperature.

(vii) *Lubrication*. The instrument is required to function correctly for 300 hours without additional lubrication.

Method of testing and permissible errors on inspection in connection with renewal of C. of A. 3. (i) The method of testing shall be as specified under para. 2. The tests will normally be carried out at room temperature (10° C. to 20° C.) and with the instrument in flying position.

(ii) The permissible errors under these conditions shall be 25 per cent greater than those specified in para. 2, unless the inclinometer is of the bubble type, in which case no increase is admissible.

C.I.S. No. 9

AIR MINISTRY

CIVIL INSTRUMENT SPECIFICATIONS No. 9

PILOT'S MAGNETIC COMPASS

(Civil instrument specifications lay down the minimum requirements necessary for the approval of instruments and equipment required to be carried on civil aircraft under the Air Navigation Directions.)

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1. The directional error of the magnet system of card shall not exceed	1°
2. The magnet system shall be constructed so that its tilt will not exceed 3° anywhere between the latitudes of 60° N. and 60° S. In England it shall be north end down by an angle not exceeding	2°
3. The magnet system shall be free to revolve when the bowl is tilted	15°
4. When the magnet system is released from rest at a deflection of 10° and at normal temperature of 15° C. the frictional error shall not exceed	1°
5. The ratio $\dfrac{\text{Magnetic moment in c.g.s. units}}{\text{the weight in grammes of the magnet system in the compass liquid}}$ shall not be less than	10
6. When at normal temperature of 15° C. the magnet system is released from rest at 90° deflection the time of swing through 85° shall not be less than	6 secs.
7. When at normal temperature of 15° C. the magnet system is released from rest at 30° deflection the overswing beyond zero deflection shall not exceed . . .	4°
8. Swirl tests—	
(i) When the compass bowl is rotated through 180° in 30 seconds the deflection shall not exceed .	10°
and the time to return to within 5° shall not exceed	20 secs.
(ii) When rotated through 180° in 15 seconds the deflection shall not exceed	20°
and the time to return shall not exceed . .	30 secs.
9. The filling liquid shall be clear and free from impurity or discoloration. It shall not freeze above	− 35° C.
10. The expansion arrangements provided shall be adequate to deal with a temperature range from	− 25° C. to + 50° C.

11. The compass liquid shall remain free from bubbles when kept for half an hour in a sealed chamber under a reduced air pressure equivalent to . . . . 10 in. of mercury.

12. The anti-vibrational suspension of the compass shall be designed so that no deflection of the card or magnet system will result from subjecting the compass to horizontal vibration of any frequency up to 2,000 p.m. and a total amplitude not exceeding . . . . ·2 mm.

13 The paint used inside the compass bowl shall not discolour, blister, crack, peel or otherwise deteriorate under the prolonged action of the compass liquid.

14. The compass shall be of thoroughly sound manufacture and constructed of suitable materials. It shall be in every way fit for the service for which it is intended and likely to remain in full efficiency for a period of at least 12 months.

15. In addition to conforming to the conditions specified above, no compass shall contain any features or characteristics which, in the opinion of the Air Ministry, are considered to be objectionable or disadvantageous.

16. In the event of a compass with unusual features being sent for examination, the Air Ministry reserve the right of adding to or amending these conditions in order to embrace all details of the compass in question.

OFFICIAL PUBLICATIONS

1. *The Airworthiness Handbook.* (A.P. No. 1208.)
2. *General Instrument Equipment for Aircraft.* (A.P. No. 1275.)
3. *Manual of Air Pilotage.* (A.P. No. 1234.)
4. *Air Ministry Civil Specifications.*

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